WHAT MODELING APPROACHES USED FOR A SUSTAINABLE RESILIENT SUPPLY CHAIN

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ABSTRACT

Covid-19 crisis has emphasized weaknesses of supply chains and pushed them to reinvent themselves and rethink the configurations adopted. The consideration of resilience in sustainable supply chain has lately played a vital role, to cope with disruptions for the business continuity. The main challenge of supply chains is to balance between achieving competitive advantage and acting sustainably. Through this paper, we review research contributions related to sustainability and resilience of supply chain. The aim to provide a holistic overview about the modeling approaches based on mathematical programming, used in the field of Sustainable Resilient Supply Chain and its applications. A primary search is set and a total of 66 papers has been analyzed to focus only the ones that include mixed programming models. Thus, 19 papers are selected, screened and studied meticulously, then categorized by modeling approach, sustainability and resilience aspects, supply chain structures and flow complexity. The resulted findings are particularly interesting for both practitioners and researchers to highlight gaps and areas for enhancement. Finally, some future research directions are suggested with issues emphasized.

Keywords: *Sustainability, Resilience, Supply Chain, Mixed Programming, Modeling.*

1. INTRODUCTION

The supply chain is the backbone of the economy that supports all these activities. Companies function because they are able to deliver to their customers. Moreover, they cannot produce a product or service without relying on their suppliers. Additionally, logistics needs and expectations have evolved with the globalization of markets and demand uncertainty, as well as with the increasing demands for reactivity and shorter lead times.

The Covid-19 crisis has highlighted the importance of supply chain resilience and sustainability. When such disruptions occur in supply chains, there is a high risk of seeing increasing repercussions. Each link in the chain becomes a little more covered, either downwards or upwards, creating an amplification phenomenon. Hence, the need to manage supply chain risks increased.

It is true that the supply chain has shown its responsiveness. The post-Covid-19 crisis has nevertheless shown the fragility of globalized supply chains, reflections and studies will therefore have to focus on new priorities: how to make supply chains more resilient and sustainable at the same time? This is a systemic approach to all the components of the supply chain. It covers all the players involved in the supply of a product, from the raw material to the end user.

A supply chain with many stakeholders makes the network more complex that includes many flows, physical, informational and financial ones. Managing these flow's processes and performance, relies on the relevance of the strategic, tactical or operational decisions taken at every level of each link of the supply chain. This complexity leads to the large number of stakeholders, to a significant diversity of flows, which must be broken down into smaller sub-chains or components to enable their analysis.

Journal of Theoretical and Applied Information Technology
31st December 2022. Vol.100. No 24

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The operational implementation of an integrated and optimized flow management is a great springboard for logistics performance. The modeling approach is much in demand and has been used as a means of optimization to be cost effective, sustainable and robust enough to face disruptive situations. Given the importance of this topic, a literature review is beneficial and important to enrich the supply chain research area.

Through this research work we aim to provide a holistic overview about the modeling approaches based on mixed programming, used in the field of Sustainable Resilient Supply Chain (SRSC) and its applications. It raises the importance of mathematical modeling in the optimization of costs and flows in supply chains. A review of the literature is carried out regarding models used for resilience and sustainability of supply chains answering the following questions:

- ✓ What are aspects of resiliency and sustainability or metrics mostly used for modeling a sustainable resilient supply chain network?
- ✓ What type of supply chain network structures considered while modeling and what are the parameters involved in network design?
- ✓ What are types of mathematical problems formulated and how they optimize sustainable and resilience supply chain networks?

To answer these research questions, we conducted a literature review process focused on sustainable and resilient supply chain mixed programming models. We contribute to the academic and research community by shedding light on the methodologies adopted while modeling, by screening objective functions, by analyzing sustainability resilience costs involved, by mapping and synthesizing solutions adopted in each context. Finding of this work would be helpful for developing other models in the future to optimize supply chain networks considering sustainability and resilience. Besides, we provide different research directions to focus on or consider in the upcoming research studies.

Our research study is different from previous works through the consideration of both concepts of supply chain resilience and sustainability at the same time as mentioned in the figure 1. Previous work treated the concepts separately [1]–[13]. In addition, the sustainability part has been the subject of interest of several researchers while supply chain resilience was of interest to only a few researchers and occupies a relatively small proportion of the supply chain sustainability [14]–[18].

Furthermore, we will take this opportunity to share our views on the topics covered by the Sustainable Resilient Supply Chain and provide recommendations for future studies to enhance this research area by drawing the connection between concepts, sustainability, resilience and supply chain, and how previous research works have been able to address them together using modeling tools. This would be helpful for the upcoming research studies, in order to better understand the subject and to know the most suitable modeling methods and those not yet explored.

A literature review is a starting point of all research process. It helps summarizing current research works by identifying issues and patterns. It generates ideas for future research trends. Several researches address the issue of modeling complex supply chains in the current literature. The purpose is to better represent relations between supply chain flows to obtain a model that approaches perfection, something that remains difficult to achieve. When it comes to the integration of the three dimensions of sustainability considering resilience aspects in supply chains models, trade-offs are, sometimes, necessary to optimize networks, processes as highlighted in the figure 1.

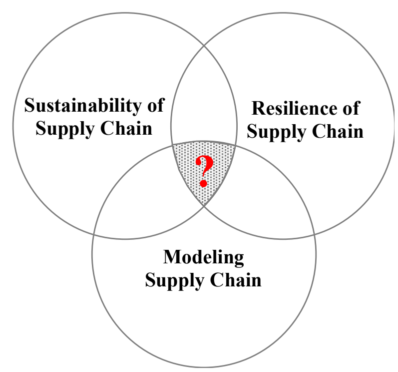

Figure 1: The Aim And Scope Of The Literature Review

This research work is structured as follows: the first section concerns related literature review of concepts and sub-research areas as a background of the present work. The second section details the methodology adopted. Further, results are presented with a focus on the sustainability aspects, resilience measures and modeling approaches. This will lead over to the third section where findings are discussed and research opportunities are highlighted. Finally, we will end up with a conclusion and future research directions.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

2. RELATED LITTERATURE REVIEW

2.1 Supply Chain Management

The supply chain received a lot of attention during the two world wars [19]. It comes from military engineering, where it has helped a lot to ensure the supply of troops, to maintain the right level of stocks of goods and weapons required, and to ensure their transport. Therefore, their main basic activities are the management of stocks of and transport. This enlightens why modern supply chains were born within transporters and wholesalers [20].

The term SCM has taken a big scale and new dimensions over the last ten years. Since 1980, it has become a common concept to both academics and practitioners [21]. According to Cooper, Lambert and Pagh [22], supply chain management is "... an integrative philosophy to manage the total flow of a distribution channel from supplier to the ultimate user." Jones and Riley [23] define it differently, "Supply chain management deals with the total flow of materials from suppliers through end users..." Following, the Supply Chain Counsil [24] state that managing supply chain Involve production and delivery effort of a final product in order to satisfy customer's customer demand for the whole chain from the supplier's supplier. In 1989, Stevens [25] highlighted the importance of Supply chain management and its role, "the objective of managing the supply chain is to synchronize the requirements of the customer with the flow of materials from suppliers in order to effect a balance between what are often seen as conflicting goals of high customer service, low inventory management, and low unit cost". In 2003, [26], [27] "Supply chain management is the coordination of production, inventory, location, and transportation among the participants in the supply chain to achieve the best mix of responsiveness and efficiency for the market being served". In other words, it means managing all the resources efficiently, the use of methods, tools and techniques to deliver a product or service to the final consumer at the right time and the right place with the lower cost possible [28].

Logistics needs and expectations have evolved with the globalization of markets and demands and the growing need for responsiveness and shorter lead times. Managing supply chain has become complex and require more agility and flexibility [20]. The implementation of supply chain management allows a better flow mastering and decision making is sometimes a real time necessity. Depending on the level of decisions in supply chain, either strategic, tactical or operational, configurations of it can be redesigned to provide an optimized network [29]. The strategic one, mainly concern location issues, production selecting, storage and distribution. In the tactical level, which is an aggregate level, concentrate on planning issues of production or distribution, transport capacities, allocation issues, etc. The last level is the operational one, where decisions concern hours or minutes, mainly are related to replenishment and delivery operations [30].

Likewise, flow complexity of supply chains takes a big part in designing supply chain. A multi-echelon system provides a configuration of multiple stages, called echelons, as a junction point where players transit or meet [31]. For instance, raw material coming from suppliers is stored and transformed at the manufacturing site, then final products are sent to central warehouse, which are on their part shipped to the distribution centers to be delivered to the end customer. This configuration, helps to alleviate and simplify the supply chain structure and provide an integrated approach that includes various stakeholders [32].

2.2.2 Modeling Supply Chain

Modeling principle consists in representing a phenomenon by and as a general system [33]. Following [33], a system in general, is the representation of a perceived active distinguishable phenomenon by its projects in a dynamic environment, in which it functions are transformed teleologically. Modeling promotes certain concerns about the openness of systems to their environment and managing their complexity [34]–[37]. Considering supply chain as a system, it helps deconstructing its component (links) and managing its complexity [38]. In a science based on experience and observation, mathematical modeling is used to represent the supply chain reality into a calculable mathematical form. It is a translation of an observation, in order to apply mathematical tools, techniques and theories to it. Reversely, the translation of the mathematical results obtained into predictions or operations in the real world [26].

In the area of sustainable resilient supply chain [10], [26], literature shows plenty of mathematical models and approaches used. The most popular methods are mathematical programming and simulation, or the combination of both of them. The use of each relies on the specificity of the problem to be solved. Usually, mathematical programming refers to optimization using objective function considering constraints and is used for high level decisions involving unknown configurations [26], while modeling by simulation aims to improve practices and risk management in a uncertain

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

environment by considering specified dynamic processes and operations of a supply chain network structure [39], or is used for more accuracy to evaluate performance of the model. Some of the models have conflicting objectives and involve then tradeoffs, commonly in the area of sustainability of supply chains [40].

2.2.3 Sustainability and Resilience of Supply Chain

Sustainable supply chains are a three-pronged challenge. The figure 2 show the combination of the green side and the social side by integrating the economic dimension represents the sustainability part of the Supply Chain Management. From the environmental viewpoint, the first definition of the green supply was set by Green, Morton & New in 1996 [23], [41]–[44] as a way where green supplies refers to supply chain innovation management considering environmental side. Stefan Seuring & Müller in 2008 [45] defined the concept of Sustainable Supply Chain Management (SSCM) as the management of capital, information and material flows along end to end supply chain considering the three dimensions of sustainable development. Ahi and Searcy [46] provide definition around GrSCM. Mostly, they focus on the economic dimension that impacts the environmental part. The majority of research emphasize the Green aspect and does not include necessarily the social side of sustainability [15], [45], [47]. Even though, the social aspect remains really important and keeps balance of the triple-bottom-line (TBL) of the sustainable development [48]. In this context, Eltantawy, Fox & Giunipero [49] focused on the social part of sustainability as ethical responsibility and highlighted the importance of selecting the suitable supplier that respects societal norms.

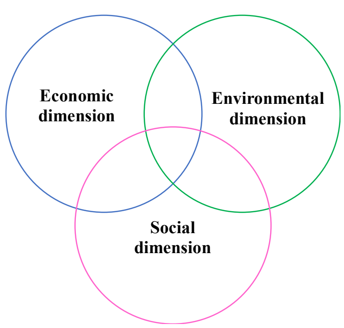

Figure 2: Sustainability Dimensions

In the organizational and business world, resilience has arised as a new concept that integrates insights of contingency and adaptation theories following Gitteli [50]. In the actual agile context where prediction of disruptive situations is hardly managed. Modeling agility of supply chain and its resilience are recent fields that attracts researchers and practitioners. It is defined as the supply chain capability to anticipate unexpected situations, to recover from disruptions by maintaining the continuity of flow management at all levels [1], [51] . A resilient supply chain must be adjustable, because in many cases the expected and wanted state is different from the original one. Christopher, in this work of Managing Risk in the Supply Chain [52], argues that resilient processes are agile, flexible and have the ability to evolve rapidly. This vulnerability of supply chains facing disruptive events, has led to many researches to look at the drivers of supply chain vulnerability [53]. Carvalho et al. [4], defines supply chain resilience as supply chain ability to face and cope with unpredictable turbulences. For a supply chain to be resilient can be summarized as follows in the figure 3:

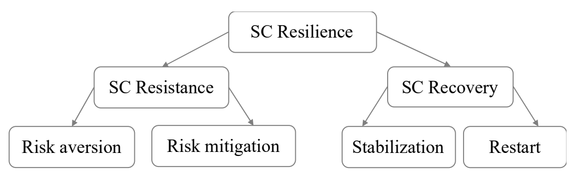

Figure 3: Resilience Strategies

According to [51], supply chain resilience must be based on two fundamental pillars as detailed in the above figure 3.

- ✓ Supply chain resistance is the ability of all supply chain links to delay disruptions and, more precisely to reduce their impact on the final product. First, attempts must be made to avoid the problem as much as possible; then, appropriate measures must be taken to mitigate its effects.
- ✓ Recovery capability of supply chain is the ability to overcome disruptions by analyzing and taking the right decisions based on results. Supply chain companies must first go through a stabilization phase, and then return to previous or better results as needed.

Supply chain resilience can be illustrated by the “resilience triangle” in the figure 4 that clearly shows how supply chain can cope with a disruptive event by controlling their processes, reducing the disruption severity and at the same time minimizing the recovery time [54]. Following Sheffi [6], the outlined graph (figure 4) explain supply chain performance affected by risk. we deduce that more the triangle is smaller, more supply chain is resilient [55].

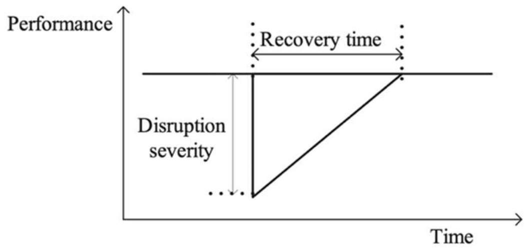

Figure 4: Resilience Triangle, Source: [54]

The Literature of both concepts sustainability and resilience, shows that they have been considered separately. Whereas, the concept of resilience is directly linked to important concerns such as ecological, social vulnerability, disaster recovery, and risk management and contribute to sustainability of economies [14]–[16], [18], [51]. An increasing interest of designing sustainable supply chains under resilience is observed from the recent reviews. Some publications explore both concepts [16], [56]. However, a sustainable-resilient supply chain still need an integrated study and can define the future of the research field, by looking for compromises between both principles and practices. Both topics still need to be studied jointly.

3. METHODOLOGY

Before leading any study, it is important to identify steps to follow and draw up a road map of the study. Conducting a literature review is a systematic and follow a clear process, relying on theoretical considerations, that details the design and analysis, based on the collection of data with a main purpose of analysis, previous research works addressed, evaluating them, discussing results, identify future research trends of the field of study. It also draws conclusions on the analyzed data. [57].

Based on a methodological point of view, we followed steps stated in the figure 5 advised by Mayring to complete our data selection and analysis process [58] and adopted in our previous research work [42]–[44]:

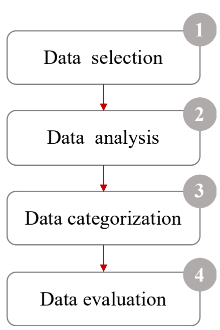

Figure 5: Search Methodology

3.1 Data selection

The first step of the study consists on defining clear bounders of the scoop, where research area is delimited and selection criteria is defined for the material of the study. It is mostly a crucial step for a literature review [8]. Inclusion and exclusion criteria are defined to delimit the search scoop. Furthermore, the data base of the search is identified and the search period is defined. Relevant keywords for the topic are then chosen after several trials.

The process in the figure 6, provides steps from the data collection to data evaluation.

3.1.1 Inclusion and exclusion criteria

As previously mentioned, the purpose of this study is to select, analyze and classify journal articles of Resilient Supply Chains integrating Sustainability.

A primary search in Scopus database was established regarding the title of papers for the period ranged from the first publication in 2010 till the 30th of June 2022. In this stage, we used the following keyword strings for the search 148 unduplicated papers are found.

(TITLE ("supply chain") OR TITLE ("logistics") AND TITLE ("sustainability") OR TITLE ("sustainable") AND TITLE ("resilience") OR TITLE ("resilient"))

A first filter was set, using search strings and selecting only “journal articles” as a contribution type, to limit our study to with 66 papers. After a first lecture of these papers, some of them seem to be irrelevant regarding the purpose of our study. Then a second filter is applied adding a second key work “mixed” and “programming” to keep 19 articles de study as shown in the figure 5. The final keyword string of the search is as follow to:

(TITLE ("supply chain") OR TITLE ("logistics") AND TITLE ("sustainability") OR TITLE ("sustainable") AND TITLE ("resilience") OR TITLE ("resilient") AND TITLE-ABS-KEY (mixed AND programming))

3.2 Data analysis

As a second step, a primary evaluation of papers is conducted subject to quantitative analysis. A formal assessment of the material selected is established by analyzing the sample of publications whom are analyzed and provided. A first insights and overview about the research area. The screening and evaluation process of publication is detailed in the figure 6, which starts by choosing SCOPUS database for the source identification. Then, relevant keywords are set to provide a first paper extraction (N= 148). For more relevancy, a document type inclusion criterion was added limiting the study to "journal articles" only. As a result, the number of research papers became 66.

In addition to criteria used in the primary search of the data selection step, we opted for the journal paper processing mixed programming models to narrow the search field for more relevant results. Hence, our research scoop concerns 19 papers as a sample of the work. Papers are scrupulously processed in order to bring out reliable findings and ensure their applicability to Sustainable Resilient Supply Chain. To examine publications, we first have a look at the title and keywords, after that the abstract, thirdly, the conclusion, then the introduction, and finally the whole paper.

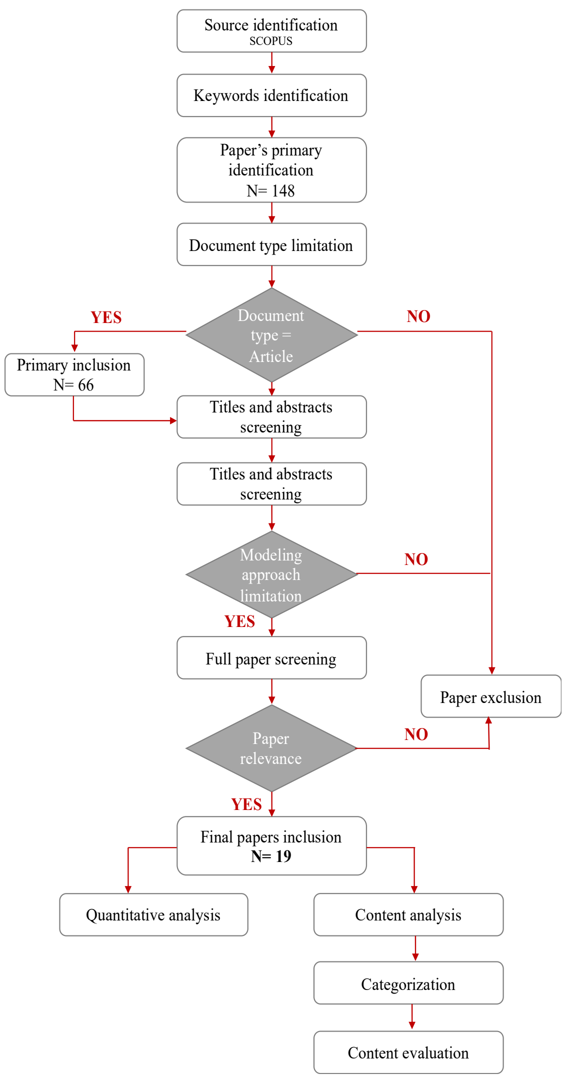

Figure 6: Screening And Evaluation Process Of Publications

3.3 Data categorization

Through the data analysis, categories are identified inductively, where major topics of the research are defined and structured as mapped in the figure 11. As a qualitative analysis, this section categorizes the study according to according to their thematic similarities and the type of their contributions. Based on the content analysis, categories chosen synthetize the content of articles reviewed and suggested a classification of them.

After a thematic analysis, and to have all-embracing vision of the topic, we identified the following three categories that simplify the analysis and the comparison of contributions:

- ✓ Modeling
- ✓ Resilience and sustainability context
- ✓ Supply chain context

The choice of these categories emanates from the relationship identified through the initial readings. The purpose of these categories is also to draw the connection between concepts, sustainability, resilience and supply chain, and how previous research works have been able to address them together using modeling tools. This categorization is helpful for the upcoming research studies, in order to better understand the subject and to know the most suitable modeling methods and those not yet explored.

3.3.1 Modeling Category

The supply chain is a real factor of competitiveness for companies. Indeed, an optimized and planned one allows the enhancement of the quality of the products, the delivery time and cost effectiveness. In an evolving context, its management is much more complex. Modeling is a better way to optimally configure this kind of supply chains, evaluating a priori several chain structures and quantifying the resources implemented, the associated costs, the energy consumption, the environmental impacts and by testing its stability and robustness in an unstable environment. In this paper, we have deemed it necessary to include the category "modeling", in order to better understand the different related sub-problems to the general optimization issues.

Furthermore, it will provide insights to researchers and practioners about supply chain problem types and models used. It could be very helpful for future studies to make a suitable model choice. Additionally, we screened all objective functions, and performed a cost analysis which allowed us to identify cost categories, such as production, transportation costs, inventory costs, set up costs, etc. This categorization also sheds light on the solving approaches adopted to facilitate model's resolution.

3.3.2 Resilience and sustainability context Category

Mastering aspects and measures of sustainability and resilience is very helpful for designing a sustainable resilient supply chain. Through this review, we analyzed addressed aspects of both sustainability and resilience and we highlighted solutions adopted to meet each. Regarding sustainability, we categorized papers via the three dimensions, namely, the economic, social and environmental dimension. Also, we provide concrete solutions used to meet each dimension such as carbon reduction, energy consumption reduction, immigration prevention, job opportunities creation, etc. On the other hand, we categorized the resilience part by uncertainty mastering, risk of disruption mitigation, etc. we also addressed solutions to integrate resilience, such as including back up suppliers, emergency stocks, multiple sourcing, etc.

3.3.3 Supply Chain context category

Nowadays, the supply chain has changed this approach to the relationship between companies. They no longer guide the process, but rather are stakeholders on all levels of decision. Through this categorization, we were able to emphasize the decision levels considered during the modeling, namely, the strategic, the tactical and operational one. This implies a type of supply chain problems to be addressed, such as location problems, which always concerns the strategic level. In addition, configurations and specificities of networks are also categorized, whether it is a multi-echelon configuration, or a multi-product network that mixes several ones, or it is time lined in several horizons, as a multi-period model. This category could be of interest to researchers, as it provides basic elements that can be the entry points for mathematical modeling of the supply chain.

3.3 Data evaluation

The last step is the material evaluation, where paper categories are evaluated by comparing results. This helps to interpret and discuss findings and propose research tracks. After the thematic classification, results where shared with the research group to compare results and discuss differences. This methodology is adopted and recommended by Seuring and Gold [59] for more objectivity, accuracy of contributions assignment and transparency. Once the confrontation is done, a final review is conducted to ensure consistency with the aim of the study.

4. FINDINGS

4.1 Quantitative findings

In this section, we will analyze the statistics of the selected research papers, identify categories for articles and discuss results to suggest directions for the upcoming research studies.

Evolution of publications

The figure 8 represent the evolution of 19 research articles of Sustainable Resilience Supply Chain, during the period ranged from 2010 to the 30th of June 2022. We note that, the number of publications is sharply increasing to reach 7 during the first semester of 2021. Clearly, modeling sustainable resilient supply chains is fertile field for researchers. It is excepted that more studies will be performed in the upcoming years due to the importance that resilience and sustainability take in the current economic context [60], [61].

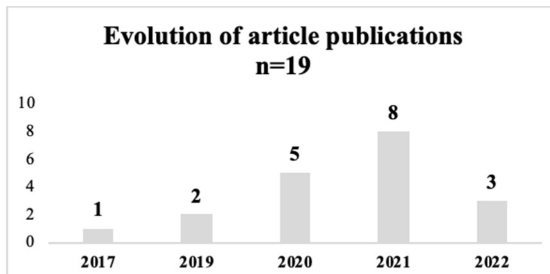

Figure 8: Evolution Of Publications

Publications by country

With regard to geographical locations, figure 9 represents the countries where research studies were conducted. The top publishing countries are Iran that holds the first place with more than 55% of the publications [62]–[70], followed by India with 18% [71]–[73]. The rest concerns UAE [74], USA [75], Brazil [76], Denmark [77] and France. Through the review of this papers, it can be concluded that emerging countries are more involved in modeling Sustainable Resilient Supply Chain, rather than developed ones. Modeling Sustainable Resilient Supply Chain, is extensively gaining interest for both researchers and practitioners all over the world.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

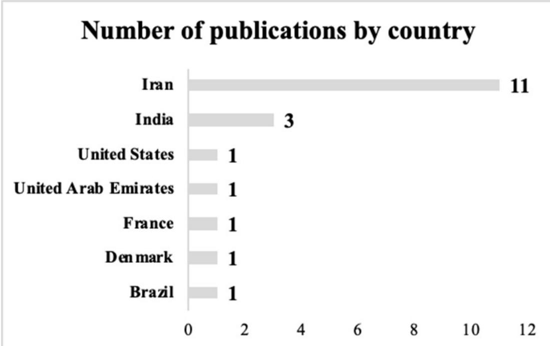

Figure 9: Evolution Of Publications

Publications by authors

The interest on sustainable resilient models of supply chains is becoming bigger. Many authors are showing this interest on SRSC throughout their contributions. The distribution of research publications is almost the same for all authors, with one publication per author except for Mehrjerdi Y.Z. who has 2 publications [65], [70].

The majority of contributions have more than three authors. We explain this by the increase in inter-institutional and inter-country collaborations. These collaborations enrich the research and allow us to see cases from different angles. Consequently, the number of authors will increase in the upcoming publications following the figure 8.

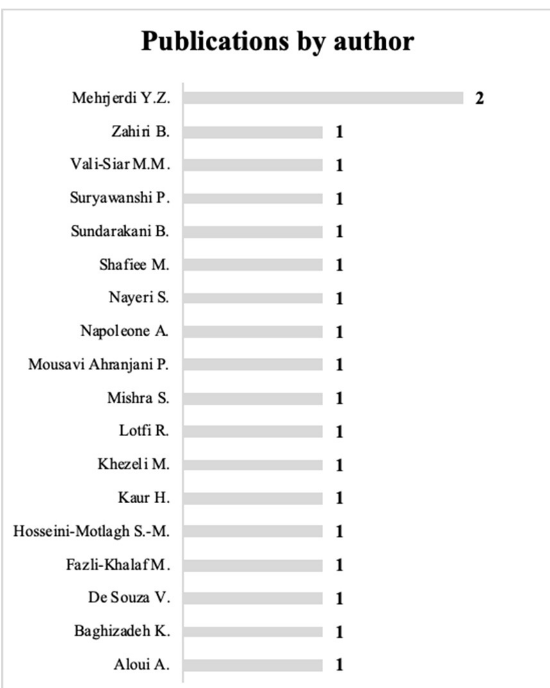

Figure 10: Publications By Author

Publications by journal

There is a large number of journal where authors published their contributions. The table 1 reports the number of publications per journal. Commonly, each journal is concerned by one contribution. Journal of cleaner production is the exception with two contributions. The majority of journals are spread out in plenty of subject areas. However, mainly papers refer to engineering field, even though contributions concern Sustainability and Resilience of Supply Chains. Noticeably, the research papers production outside the field of engineering reflect the growing interest of modeling sustainability and resilience of supply chains.

Table 1: Contributions By Journal

Journals	Number of contributions
Annals of Operations Research	1
Applied Energy	1
Clean Technologies and Environmental Policy	1
Computers and Industrial Engineering	1
Environment, Development and Sustainability	1
International Journal of Advanced Operations Management	1
International Journal of Industrial Engineering and Production Research	1
International Journal of Logistics Management	1
International Journal of Supply and Operations Management	1
International Journal of Systems Science: Operations and Logistics	1
Transportation Research Part E: Logistics and Transportation Review	1
Mathematical Problems in Engineering	1
Numerical Algebra, Control and Optimization	1
Sustainability (Switzerland)	2
Sustainable Production and Consumption	2
Journal of Cleaner Production	2

Industries addressed

We note a diversity of industries in which the studies were conducted. More than 60% design their SRSC models by applying to an industry. 32% of cases were general and does not specify the application sector of their model.

Table 2 shows the sectors concerned by contributions. The most concerned industry, is the automotive one, with 5 contributions, from car assembly, tire industry and others. In second place, we find the energy and agri-food sectors. The three other remaining cases are related to the

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

pharmaceutical industry, apparel and water heater industry.

The diversity of applied industries cases supports the idea that the resilience and sustainability of supply chains does not concern a specific sector but all existing ones. This range of application sectors creates a richness in the research area and is very helpful to see different types of models, the most used in a given industry, and to identify the specificities of each.

Table 2: Concerned Industries By Model Design Of Sustainable Resilient Supply Chain

Not specified	6
Automotive industry	5
Energy industry	3
Agri-food industry	2
Other	3

4.2 Content findings

In this section, we expose results of the review analysis classified following categories previously identified. The analyzed contributions have many similarities which makes categorization easier. The first category provide us an overview about modeling approaches using mathematical programming. The second one covers aspects of sustainability and resilience in the supply chain context, the last one goes around the supply chain structure, problems and the related level of decisions.

4.2.1 Modeling approaches

In this category we review the principal characteristics of the modeling approaches used for sustainable resilient supply chain issues. There is a variety of models proposed explained by the diversity of industrial contexts. The table 3 summarizes modeling approaches and tools assigned to each publication deductively.

Models are whether linear or non-linear, single-objective, bi-objective or multi-objective. The majority of them are MILP models, more than 13 contributions [62], [65], [67]–[70], [72], [74]–[76], [77]–[79], the rest concerns 5 MINLP models [64], [66], [71], [73], [80] and 1 MFPFP [63]. Some of the models [64] were non-linear were linearized to simplify their resolution. The inclusion of uncertainty was treated using fuzzy approach [63], [66], [68]. Likewise, we identified 3 types of models, multi-objective ones with more than 10 contributions [62]–[68], [70], [73], [75] divided in many sectors, namely, tire industry, water heater, electricity or pharmaceutical industry. The bi-objective models are subject of 3 models [69], [76], [77] mainly in lignocellulosic bioethanol and sugar beet supply chains. Finally, 4 single objective models [71], [72], [74], [80] related to food supply chain and apparel industry. 14 of the research papers adopted a multi-stage or scenario-based modeling approach either to test the model under disruption, or to make a primary model including only sustainability criterias and then integrate the fuzzy logic in order to mitigate the risks of uncertainty.

Table 3: Modeling Approach Codes And Number Of Related Papers

Programming approaches	Concerned papers
Stochastic Programming	10
Robust Programming	2
Possibilistic Programming	1
Stochastic Robust Programming	3
Stochastic Possibilistic Programming	2
Robust Stochastic Possibilistic Programming	1

To go deeper in our analysis, four classes of programming approaches are identified, stochastic, robust, possibilistic and hybrid ones. Hybrid models are a class of mixed characteristics. It combines at least 2 programming approaches. Noticeably, they are a multi-objective model and depend on multi modeling tools.

Implementing resilience requires mastering uncertainty, in this case, several authors opt for stochastic programming, around 10 authors [65], [67], [70]–[73], [76], [77], [79]. It was observed that only few authors are inclined to build robust and possiblistic models. In single objective model [74] used goal programming to handle multiple conflicting objectives measures.

The number of research papers of hybrid programming is around 5 spread out respectively as follows, 2 for the stochastic robust programming [62], [68], 2 for the stochastic possibilistic programming [66], [75], and 2 for the Robust stochastic possibilistic programming [69], [78].

Table 4: Related Papers To Programming Approach

Modeling approach	Code	Concerned papers
Mixed Integer Linear Programming	MILP	13
Mixed Integer Non Linear Programming	MINLP	5
Mixed Fuzzy Possibilistic Flexible Programming	MFPFP	1

The major objective in integrating sustainability and resilience in supply chains, is to strengthen the capability of supply chain links to resist and recover quickly from disruptions with minimal costs and still be as sustainable as they were before or more. The reviewed formulated problems were elaborated with variety of objective functions. Prominently, the multi-objective models include on average 3 objective functions, mostly concern the minimization of total cost of supply chain, the minimization the environmental impacts and maximization of the social impact. In addition, some mathematical models include a fourth function regarding the energy consumption minimization or the non-resiliency of the model minimization as presented in the table 9.

Mastering costs along a network promotes a more efficient, sustainable and resilient supply chain [81]. We found it necessary to perform a costing analysis along the supply chain network, to identify and group them into cost categories. The majority of functions include costs related to activities within the Supply Chain network. Table 10 list the costing categories related to supply chain. We found 10 categories with 37 costs, namely, overall costs, purchasing and procurement costs, inventory costs, production costs, transportation costs, set up costs, warehousing costs, resiliency costs, sustainability costs and other costs used for some specific issues. Some costs are called differently by the authors, but concern one and the same cost. Therefore, we have proceeded to a unification of the names in order to make the classification easier. The most popular ones are the total, transportation and carbon footprint costs. More than 10 models used the total cost in their formulated problems [62]–[64], [67]–[74].

We performed a review on solving approaches used for each case and identified more than 10 solving ways to the mathematical models as presented in table 10 in appendix that can be heuristic or metaheuristic ones. The distribution of solving methods is almost evenly spread out. Commonly, the ε-constraint method the classic, improved or augmented version is widely used with 4 contribution [65]–[67], [76]. Followed by the chance contrained approach used with 3 formulated problems [69], [72], [73]. 2 other contributions used goal programming either the multi-choice or fuzzy one [62], [68]. The rest concerns Pareto-based lower bound, Piece-wise Approximation, Utility function one each [71], [75].

As a further issue, some authors additionally used simulation to provide insights regarding applicability and performance of the model used or explain and predict the behavior of real-world systems. Some authors have used exact methods to solve their models, 6 of them has not used simulation tools. Some others used exact solvers like CPLEX, LINGO, NEOS, and LINDO [64], [65], [69], [70], [72]–[74].

Regarding few issues, especially stochastic programming ones that deal with disruption scenarios, meta-heuristic algorithms have been applied such as Monte Carlo algorithm [66], [71], [79].

4.2.2 Resilience and sustainability context

The table 11, shows publications that addresses sustainability aspects in their models. All models, somehow, consider the economic and environmental dimension of sustainability. On the other hand, only 12 contributions, which represent more than 60% of paper references, [62]–[68], [70], [75], [77]–[79] consider the three dimensions of sustainability in their models namely the economic, environmental and social ones. Many previous reviews made the same point [82]. The social part is less performed in models to cover the whole sustainability dimensions [10], [83], [84].

Various sustainability solutions were integrated to meet sustainability goals. The environmental aspect can be measured by many possible indicators, the most well-liked metric, is the carbon footprint reduction which occupies the first position regarding our sample of study. All contributions mostly used it in their objective functions as an environmental cost minimization. Energy consumption, was integrated by only 3 contributions [64], [65], [70], natural ressources use or consumption was also considered by two models [63], [65]. Otherwise, the rest of measurement solutions concern the social performance of models. Job opportunities creation is covered by 9 papers [62]–[68], [70], [75], models considering the social part of sustainability include the job creation maximization in their objective functions. Finally, the improvement of the Economic development rate took place in 3 models [68], [75], [77] followed by immigration prevention, safety and accident rate one each [63], [79].

As far as supply chain resilience building is concerned, mastering risk and uncertainty are tremendously important [85]. Indeed, more than 14 papers consider uncertainty in their models [62]–[66], [68], [69], [71]–[75], [78], [79] while others deal with risk of disruption (15 papers) [63]–[65], [67]–[74], [77]–[80] as mentioned in the table 5. Other key drivers of resilience have been raised in the models such as flexibility, robustness and

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

accessibility, 4 each. Besides, through literature we identified the key characteristics of supply chain resilience [54], [86], as detailed in the figure 3, all authors (19 models) choose a strategy of risk mitigation [63]–[80], [87] for the recovery part. On the other hand, the stabilization and activity restart strategies are almost the same, respectively 8 [62], [66]–[68], [70], [72], [76], [77] and 5 each [62], [67], [68], [70], [76]. Only few papers tested the model under disruption for the resiliency to see how vulnerable their supply chain network is.

Table 5: Resilience key charachteristics

Resilience strategies	Concerned papers
Risk aversion	7
Risk mitigation	18
Stabilization	8
Activity restart	5

Next, we reviewed solutions provided by authors in their formulated models to implement resilience. Various solutions are provided, it can be either mathematical or conceptual ones, or both. The mathematical resilience solutions are detailed in the modeling category. Regarding the conceptual ones, they are plenty detailed in the table 11. Some of them are applied in supply chain network design and include service level, maintaining flows, node complexity, node criticality, and flow complexity minimization as resilience measures. Some others came up with conceptual solutions for the upstream or downstream supply chain, namely, Information Sharing, Multiple sourcing, Back up supplier, Prepositioning Inventory, Backup Plan, etc.

4.2.3 Supply chain context

The supply chain context has become very complex to manage. However, splitting it into task categories or structures can be very helpful to clarify the process and the relation between links. Through the present work, we reviewed supply chain structures used in the concerned papers. The identified SC structures can be divided into three design types, namely, upstream, where the main activities are related to suppliers, downstream that concern post-manufacturing activities, and finally, a closed loop structure where the reverse flow is incorporated [88]. 11 models deal with the closed loop configuration [63]–[66], [70], [72], [78], [80] while others are subject to upstream and downstream supply chain with, 10 and 8 each respectively, as shown in the table 6. Besides, six authors deal with both upstream and downstream supply chain in their models jointly [62], [67], [68], [74]–[76], [79].

Table 6: SC structure

SC configuration	Concerned papers
Closed loop	11
Upstream	10
Downstream	8

Managing multi-echelon supply chain has received a lot of attention in recent years. It is a distribution system composed of several functional levels called echelons [38]. Each in turn, is made up of numerous sites composed of producers, distributors, retailers, suppliers and customers. Echelons of a supply chain often determine its complexity [87]. Hence, we considered it essential to review supply chain configurations and their flow complexity. After screening models, we noticed that an average of 15 models are designed in a multi-echelon network. Some of them are not explicitly mentioned by authors. Besides, only few models, around 3, consider a number of products simultaneously with at least one correlating factor, such as cost or storage constraint, called multi-product models [62], [71], [72]. Another factor that complexify structure of networks is the time horizon. 7 models are multi-period [63], [66], [68], [69], [72], [75], [78].

Managing supply chain requires a number of decisions to be made in order to satisfy the customer's demand in the required delays. These decisions can be gathered into three hierarchical levels [34]–[37], first one is the strategic, that determine the structure of the chain. The second level is the tactical, that is based on the allocation and the use of resources as well as on the modalities of circulation of products in the structure designed at the strategic level. The final and third level is the operational one, where decisions are made to ensure the proper management of supply chain resources within each facility, as well as between facilities, in the short term. These levels vary in each scope, following the degree of the decisions they involve, and according to the respective time dimensions [34]–[37]. Through this review, it is clear that some formulated models include a multi-decision level horizon, mostly the strategic and tactical one as detailed in the table 7. More than 12 formulated problems consider the strategic level of decision in their supply chain [62]–[64], [66]–[70], [72], [74]–[76], [77]–[79]. Rarely, the tactical level is dealt with on its own [65], [71], [73], generally it is an aggregated level and its decisions are derived from the strategic level. In the formulated issues, two

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

models consider the operational level of decision [67], [80].

Table 7: level of decisions by contribution

Level of decision	Concerned papers
Strategic	15
Tactical	8
Operational	3

Categorizing supply chain problem types help considerably to better define the problem and model it. Authors proceed with different ways in formulating their models. Based on the work of [89]. We reviewed papers following the framework suggested by Noha A. Mostafa. There are many supply chain issues tackled by authors, as shown in the table 8. The distribution of SC issues reveals that much emphasis is given on production distribution problems [62]–[64], [67], [70], [72], [77], [80], location problems comes in a second place [66], [68], [69], [72], [74]–[76], [78], [79]. Each contribution can be subject to one supply chain problem or more.

Table 8: Supply chain formulated problems

SC problems	Concerned papers
Production distribution	8
Location allocation	4
Location	6
Distribution planning	1
Supplier selection	1

5. DISCUSSION

In this section, we will try to cover studies that has been done in the context of sustainable resilient supply chain design and management. We will discuss findings of each category presented at the methodology section.

5.1 Modeling

The easiest way to incorporate sustainability metrics in a model, is through a single objective one. Indeed, the majority of MILP models are multi-objective ones due to their complexity incorporating resilience aspects with the sustainability ones. Multi-objective models are not easy to solve [62]–[68], [70], [73], [75], [78]. Epsilon (ε)-constraints approach is used by [65]–[67], [76] to prioritize a primary objective and consider others as constraints. While Chance constrained approach [69], [72], [73] is applied to solve mathematical formulated problems modeled under numerous uncertainties by making sur that a certain constraint is above a certain level. The application of it include many stochastic parameters, such as time recovery, expected capacity, which is very interesting for supply chain resiliency. For instance, it was used by [72] in their model to deal with the dynamic production and storage capacity through obtaining the deterministic equivalence of the stochastic demand and returns. [77], used a mixed integer programming (MIP) algorithm for a strategic network design based on indexing and assessing the reusability of technical resources, comparing different network configurations in order to identify the reusable and reconfigurable resource candidates.

As previously mentioned in the section of findings, most of the models are MILP ones which undoubtedly facilitate the resolution using some solving tools such as LINGO, CPLEX or other solvers [64], [65], [69], [72]–[74]. Multi-objective, bi-objective or single objective models can be totally or partially solved using solvers with weighted sum or ε-constraint techniques using solvers.

On the other hand, MINLP concern few formulated models, [66], [78] solved by Lagrangian relaxation method that provides a robust solution with an upper and lower bound for the optimal value of the objective function, also the model was decentralized into two-stages. Other authors [64] linearized the formulated model by removing the absolute value function until obtaining an optimal solution using LP-Metric. While [73] used a MINLP model to deal with various uncertainties in the carrier selection. [80] Had a MINLP model too, applied on the petrochemical industry and using a real case of gas refineries, with a main purpose to satisfy customers demand by minimizing the total cost of transportation.

In some very complex models, like [66], [71], [75], it is almost impossible to find an exact solution. The use of metaheuristics is necessary to find an approximation of a better solution such as Monte Carlo algorithm and DVG algorithm.

The use of uncertainty in the various models is very common. It is performed by fuzzy programming with stochastic programming. A large part of models is either stochastic or combined with another programming approach. [66] to deal with uncertainty, a fuzzy programming was employed and solved by the improved epsilon (ε)-constraints approach. The latter is used to transform a multi-objective to a single-objective problem. [79] Used a multi-stage programming in a single objective model to deal the complexity of the network by determining the distribution centers to be opened, the allocation of retailers and suppliers, the inventory levels as well as the routing of shipments in each period. The model was solved using Monte Carlo and sample average approximation method.

All kinds of mathematical programming, either stochastic or hybrid are a complementary modeling approaches that offer suitable solutions of resilience and sustainability in a SC network.

Furthermore, the effectiveness of many models is tested in disruptions either for natural disasters, or, pandemic situation, or, political instability for more reliability. Noticeably, there are two types of modeling of resilience and sustainability, either the model is developed including sustainability metrics than tested under disruption for the resiliency part such as [76]. Or, a model that includes both resilience and sustainability metrics in the same model [62], [63], [66], [75] than it is tested under disruption, to provide two scenarios, one where the model is optimized without disruptions and the second one optimized under disruptions, as it is the case of scenario-based models [69], [76]. From that point on, mastering uncertainty take a huge part in modeling, as it provides some mathematical solutions to meet resilience, the conceptual ones, are discussed in the section of resilience and sustainability context. Clearly, modeling supply chain under uncertainty remains an emerging problem. It still need to be explored and combine more programming approaches even if the stochastic one remain the most popular [65], [67], [70]–[73], [76]. Indeed, literature shows that robust and possibilitic approaches has not been well-studied and rarely used. Thus, exploring both of them in modeling supply chain provide interesting results.

The major, multi objective models developed more than three objective functions. Commonly, the first one concerns the total cost minimization, the second one is about the environmental impact minimization and the third one, is about the social impact maximization. In some cases, the fourth objective function may concern the energy consumption minimization [64], [70] or the reliability of the network maximization [63]. Regarding the resiliency concerns, [69] has adopted a different strategy, which is based on two objective functions, the first one aims to minimize the total cost without disruption scenarios and the second one with a disruption scenarios. Another particularity which is noticeable, concern an objective function which includes the minimization of the non-resiliency of the model. It is a novelty used by [66], that take various resilience measures into consideration in designing a resilient network of the electricity industry. This could be a good avenue to explore for future research. How to integrate resilience metrics into objective functions? And how to minimize vulnerability in the network along the supply chain and keep it sustainable? Modeling resilience still need deep studies as well as the social part of sustainability that include only few parameters in objective functions. Similarly, many other studies [90]–[92] has reported and highlighted many resiliency metrics that could be included in the future studies. Another interesting way to include resilience metrics is used by [77] that consider reconfigurability of machines and collaboration between stakeholders.

After conducting a cost analysis, we observe that most of mathematical models aim to optimize supply chain costs. Mainly, objective functions aim to minimize the total cost by satisfying customer's needs [48], [50]–[55], [57], [58], [60], [61. There are some specific costs used by authors and related to the area of application [76], [79]. Moreover, some costs are the most popular ones, such as, total cost, transportation cost and carbon emission cost. This is necessarily due to the integration of one or more dimensions of sustainability. For instance, transportation cost and carbon emission cost are closely related to the environmental dimension, while total cost, and generally aims at optimizing the efficiency of the supply chain and thus covering the economic dimension of sustainability. Energy consumption cost [64], [65], [70] is rarely considered in objective functions and can be more used in the upcoming studies. Regarding the social impact, it is generally covered by the job opportunities creation cost [62]–[68], [70], [75], [77], [78]. After screening and analyzing objective functions, it is noteworthy that some cost can be either fixed or variable. For instance, the job opportunities cost is variable in some cases where the model includes seasonal job. Besides, the cost clustering we provided, can be very helpful for further studies to identify potential costs related to each part of supply chain related to resilience and sustainability. It is interesting for future studies to include a cost related to the disruption impact while modeling resilience in SC network.

Most of the papers are industrial cases, which make results interesting and enriches the research area with new solutions [62]–[65], [68]–[71], [74]–[76]. More than 60% of the cases has directly applied solutions to different industries. Few others research articles used industry cases to illustrate and validate and explain the modeling approach adopted.

However, the specificities of each industrial context, sometimes makes the model more complex. Hence, some difficulties in their solution can be revealed and authors look for metaheuristics as alternatives of faster solution methods. For instance, [76] designed sustainable Supply Chain of a sugar beet supply chain using the ecosystem network analysis (ENA) to evaluate resilience. [63] Addressed a multi-objective model using Mixed Fuzzy Possibilistic Flexible Programming to immune the network against disruptions the tire industry. Another interesting application area, was in the pharmaceutical industry, used by [75] to design a network based on a multi-period planning horizon under uncertainty. Besides, real world application is commonly MINLP model due to its complexity [64], [66], [71], [73], [80]. Prominently, there is a diversity of industrial cases, however, the complexity of real-life systems is something still to be explored.

Some significant contribution emerges while modeling, few models are generic without a specific area of application. Adding the criteria of resilience to those of sustainability makes the development of generic models more complex [66], [67], [72], [73]. For future studies, generic models could be simulated in real world cases to test their reliability.

Last but not least, the relation between supply chain problem types and modeling approaches is perceptible. The majority of models tackle location issues [66], [68], [69], [72], [74]–[76], [78], [79] either capacity or facility location. Thus, node complexity, node criticality of the network, are more often used is these cases for selecting the best possible choice for distribution, manufacturing plants, collection centers, etc. the second problem types addressed are production distribution ones, mainly covers multi-objective models due to the multiple stakeholders in the model. Other SC issues have received less interest such as production and procurement or supplier selection [65] as detailed in the table 11. Generally, modeling more understandable issues creates the opportunity for more optimization. It is highly recommended to identify the type of supply chain problem in order to better define it and facilitate its modeling [89].

5.2 Sustainability and resilience context

Improving sustainability is no more a choice for supply chain practioners and researchers. It is important for a supply chain to be economically efficient, socially inclusive and responsible, and environmentally friendly.

The economic dimension is a primary enabler of sustainability in supply chain. It is logical that economic issues are the most addressed since most practitioners are looking for profitmaking. In the reviewed research papers, all authors, integrate this dimension by minimizing costs in the objective functions, mainly total cost of the network [62]–[64], [67]–[74], [78]–[80]. However, profit maximization is not subject of any objective function while previous studies in management include it in their objective functions [93], [94]. Indeed, the implementation of the economic dimension remains to be explored in other ways by developing other economic performance criteria in supply chain. Extending the economic dimension to more solutions would be an opportunity for future contribution.

Regarding the environmental impact, it is mainly dominated by the carbon emission minimization which can be explained by supply chain issues performed by authors [62]–[67], [70], [75], [76], [78]. Most of supply chain problems concern production and distribution or location. As a result, models deal with transportation matters more specially carbon emission reduction. In the same way, many previous studies focused on the environmental impact while modeling [95], [96], and the optimization concerned mainly carbon footprint reduction.

Moreover, supply chain problems that consider the social part of sustainability are focusing on the production and distribution part, which can be explained by the need of job opportunity creation or employment rate enhancement [62]–[66], [66], [67], [75].

Resilience takes a big place, especially after the covid-19 health crisis. The awareness of managing its complexity is growing and becoming tremendously important, particularly when the majority of activities are outsourced and globalized. Nowadays, designing a supply chain should consider strategies based on risk management (aversion or mitigation), recovery in case of any disruptive event, by adopting proactive and reactive strategies [54], [97]–[101]. For some cases, the evaluation of scenarios generally concerns the level of sustainability of a SC in a disruptive situation. [80] Adopted two modes a normal and resilient one, then results were applied at each level. When a disruptive situation and certain members of the Production network fail, the resilient scenario is applied. The scenario-based approach is very interesting for collaborative supply chains and for companies with common interests. In the same way in a manufacturing context, [77] used a mixed integer programing algorithm to identify and compare machines by their reusability and reconfigurability while designing the network. The geographical locations were used to improve supply chain resilience and sustainability.

These problems are usually a matter of distribution and production. Where they evaluate how resilient and sustainable is a supply chain in a disruptive situation. Many previous cases confirmed the relation between sustainability and resilience [14]–[16], [18], [56], [102]–[104]. It could be either a win-win situation or trade-off. Many cases that deal with different scenarios in their modeling, are trade-off situation between sustainability and resilience [65]–[67], [71], [74], [76], [78], [80]. On the other hand, win-win situations between sustainability and resilience concern the papers that consider resilience solutions into their model [62]–[64], [68]–[70], [72], [73], [75], [77], [79]. In the same way, authors provide various types of resilient solutions or practices such as including back up supplier, emergency stock, buffer capacity, multiple sourcing, etc [62]–[71], [74], [75], [77]–[80]. Such as [71], who used a the most sustainable back up supplier as a primary action to enhance resilience strategy in designing the SC network. While [65] choose the multiple sourcing strategy that provides better results compared to single sourcing.

Some conceptual solutions are more important for sustainability, in practice, they are mainly the backup supplier, information sharing, and multiple sourcing, while using single sourcing, less stored inventory, and less redundancy. On the other hand, node complexity, node criticality, provide solutions for the resiliency of the network particularly for location problems. Some other resilience metrics are considered while modeling such as restart cost [79] or capacity expansion [64], [78]–[80].

We believe that many resilience solutions or practices could be an effective strategy to mitigate SC disruption. However, this field still need to be developed in conjunction with the sustainability dimensions. Future research should tackle more closely both resilience and sustainability issues, especially while modeling. Generally, it is a matter of trade-off strategy [67], [76] between sustainability and resilience. A win-win strategy is mostly recommended. The scenario-based model could be supplementary to assess the robustness of the supply chain network. It is interesting for future studies to include a disruptive cost while modeling resilience in SC network.

5.3 Supply chain context

Complexity is present in the supply chain at different levels. In products, complexity is related to the product portfolio through the number of references or components. In the processes, the complexity is related to activities in the supply chain, manufacturing, distribution, procurement … and also related to the volume of information to be processed to carry out these processes. And in the structure, to the complexity of the network through the number of stakeholders involved in the supply chain. Through the analysis of papers and models, we have distinguished several elements that make the supply chain more complex. Namely, the configuration of the supply chain network, either it is multi-echelon, or a multi-period horizon, or a multi-product managed network. Several supply chains are designed as multi-echelon network [62]–[68], [70], [72], [76], [99], [105], [106], [78]–[80]. In fact, many authors have multi-echelon network configurations but do not explicitly state this in their studies [64]–[68], [76], [99]. It is through the screening and analysis of the models that we were able to detect the configuration of the supply chain network. This is explained by the desire to simplify the network into blocks of stakeholders (production site, distribution center, suppliers ...) and the desire to reduce transport costs. The supply chain network is therefore, more often than not, composed of several levels or storage sites. Hence, the need to approach the problem by considering all levels of the chain. Multi-echelon systems are difficult to analyze since decisions made at one site are directly linked to decisions made at other storage sites [87]. Therefore, some level of coordination between different levels is preferable in order to reduce total inventories and replenishment costs. Several strategies have been put forward to manage the supply of multi-echelon systems. In addition, it is notable that an increase in the number of echelons often results in a reduction in transportation costs, an increase in inventory and lead times, but a significant reduction in transportation costs [31], [32], [107].

The levels of decisions in supply chain are generally classified according to the time horizon and the degree of importance. During our paper analysis, we have detected 3 levels of decisions, namely the strategic level which are generally long-term decisions, involving heavy investments and which determine the structure of the supply chain, such as the problems of location of sites, site capacity, selection of supplier... etc [62]–[64], [66]–[70], [72], [74]–[76], [77]–[79]. Tactical decisions are medium term, from a few days to a few months.

They consider logistics needs, distribution, network flows, and inventory and production planning and mainly concern supplier, product, or site allocation issues, as well as the sizing of inventory levels [65], [71], [73], [79]. Operational decisions typically have a very short horizon of a few days to a few months [67], [79], [80]. They consider the decisions of the higher strategic and tactical level to program the delivery, the allocation of the means of transport to the sites, the selection of initinary... etc [67]. Most of issues are strategic ones, this can be explained by the type of SC problem which mainly concern location issues and production distribution. On the other hand, we noticed that most of the models considering several decision levels, for example the strategic and tactical levels, are multi-period models [63], [68], [69], [99]. This is due to the nature of the supply chain problems treated by the authors. The majority of authors focuses on overvall supply chain network design to which explain the fact that models consider multi-decision levels, namely strategic and tactical. Authors [62], [64], [70], [72], [106], [77], [78] exclusively considered the strategic decision level while modeling, this is due to cost optimization on a high scale and could have a positive impact on other decision levels. There is a lack of strategies while modeling in the operational decision level.

Optimization by decision level was mainly concerned with sustainability. There are only a few authors who integrate resilience into each decision level. Efforts in this direction can be developed, including resilience in each decision level. Or, it could be an overall optimization based or not on a resilient or non-resilient scenario such as [79].

Regarding supply chain structure, there are many authors that studied a closed-loop supply chain network [63]–[66], [70], [72], [78], [80]. It is interesting to integer the reverse part to the upstream and downstream, either for product reuse or recycling. Most of closed-loop SC concern the Car industry sector [63]–[65], [70], [78], which can be explained by the nature of materials used mainly non-biodegradable like plastic, heavy metals and so on. Closed-loop supply chain is a good structure for sustainable initiatives. It conserves more natural resources and minimize raw material cost [63]–[66], [70], [72]. Regarding resilience, closed-loop supply chain mainly used node complexity and flow complexity to handle disruptions and be more resilient [62], [66], [74], [75].

6. CONCLUSION

There are noticeable growing considerations for practioners, academics and researchers on the field of Sustainable Resilient Supply Chain (SRSC) due to consciousness of customers and the urgent need to be more competitive in a context of globalization.

Through this research work we provide a comprehensive review of modeling approaches used on Sustainable Resilient Supply Chain. Besides, during the last ten years only few reviews were conducted combining mutually resilience and sustainability in their study. Our literature review contributes to reduce such gap and provide insights for future studies.

Various previous studies [10], [37], [101], [108] studied modeling supply chain resilience and sustainability and network optimization, and provided an overview and listed approaches adopted in each supply chain problem, which are interesting and helpful for advanced analysis Indeed, what distinguish the present study from the previous ones, is the focus on mixed programming approaches performed by authors to incorporate resiliency and sustainability in supply chain networks. It provides an accurate analysis of mathematical models structure and solutions adopted in each case. Moreover, this literature review enhances the research area of sustainable resilient supply chain by drawing the connection between concepts, sustainability, resilience and supply chain, and how previous research works have been able to address them together using modeling tools. This would be helpful for the upcoming research studies, in order to better understand the subject and to know the most suitable modeling methods and those not yet explored.

Within the conducted study we addressed, and aimed to answer 4 questions, (i) What are aspects of resiliency and sustainability or metrics mostly used for modeling a sustainable resilient supply chain network? (ii) What type of supply chain network structures considered while modeling and what are the parameters involved in network design? (iii) What are types of mathematical problems formulated and how they optimize sustainable and resilience supply chain networks?

We started by setting the scene regarding the two concepts of resilience and sustainability, adding to this the current context of the supply chain through some literature. Different authors and conceptual related concepts were identified, which helped us in the next section of quantitative and qualitative analysis. Then, a sample of 15 papers has been screened and assessed to bring out approaches and techniques used for the mixed programming models. Some significant contributions arise from our study and led to the identification of research gaps listed in the research directions section. In this sense, some research opportunities were proposed for the upcoming studies.

We point out modeling approaches used, that commonly concern mixed integer linear programming, and fuzzy programming. They are the most used approaches form only a subcategory of the large range of existing methods. The literature concentrates on multi-objective problems because modeling issues of sustainability and resilience of supply chain by nature are multi and include many factors in their objective functions, either constraints or parameters. They cannot be modelled in a single-objective model unless the objective function include the cost equivalent of all factors. Solving tools are always an important part to be addressed because it tackles the complexity of models. Solvers such as LINGO, GAMS, CPLEX were used for solving MILP models, while in some complex cases, the use of metaheuristic methods is tremendously important to solve models and provide the best solution possible.

Regarding programming techniques, stochastic is the most popular one, some of them combine two or more techniques as a complementary solution that suits the resilience part. Uncertainty is a characteristic of the majority of models and usually mastered using stochastic programming. Robust and possibilistic programming still need to be explored in future studies.

An average of 3 objective functions is included in models and mainly concern, environmental emission and total cost minimization and social impact maximization. Only few models dedicate an objective function to resilience, either for the minimization of the non-resiliency part or the maximization of the flexibility and resiliency of the network. Through this research work, we provide a cost clustering that can be very helpful for further studies to identify potential costs related to each part of supply chain related to resilience and sustainability. It might be interesting for future studies to include a disruptive cost while modeling resilience in SC network.

Real world application and industrial cases often make model more complex and require heuristics or metaheuristic solutions. However, it brings out interesting results for practioners.

Regarding sustainability dimension, the economic side of sustainability is the most addressed part with a cost minimization function or cost profit maximization. It is obvious that the environmental side visibly dominates and social aspect which is rarely considered or is only limited to one or two metrics. The social dimension is a challenging part to model. Because it is a broad aspect that encompasses several concepts that are sometimes difficult to calculate.

Up to now, research on supply chain resilience is still dominated by uncertainty control. As already mentioned, there are two ways of modeling resilience and sustainability. The first one is about developing a sustainable model and test it under disruption for the resilience part. The second one, incorporate sustainability and resilience metrics in the model. Moreover, while analyzing authors models, several conceptual solutions of supply chain resilience where identified. However, this research area still needs to be developed. The scenario-based approach for resilience is very interesting for collaborative supply chains and for companies with common interests. In the same way, it would be beneficial if governments and companies encourage databases sharing for a collaborative resilience and sustainability. This will additionally require the adoption of new managerial approaches.

The relation between sustainability and resilience can be either a win-win situation or trade-off. Cases dealing with different scenarios in their modeling, are trade-off situation. While, models that include resilience sustainability solutions into their model are win-win situations. Some conceptual solutions are more important for sustainability. They concern mainly the backup supplier, information sharing, and multiple sourcing, while using single sourcing, less stored inventory, and less redundancy.

Reviewing supply chain context, the most common problems concerns production distribution and location one, while some of them integrate additionally supplier selection issues. It is noticeable that there is a link between supply chain level of decision and problem types. For instance, location issues concern the strategic level, while allocation issues concern the tactical one. The majority of the reviewed papers, consider the strategic level which can be explained by the cost optimization on a high scale and could have a positive impact on other decision levels. However, there is a lack of strategies when modeling in the operational decision level. Optimization by decision level was mainly concerned with sustainability. Only a few authors integrate resilience modeling into each decision level. Efforts in this direction can be developed, including resilience in each decision level.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Many elements make the supply chain more complex, and its configuration can be multi-echelon, multi-product or multi-period horizon. Commonly, papers studied are multi-echelon configurations but do not explicitly state this in their studies. It is noticeable that the more echelons are added to the network, the more the network is resilient and sustainable. However, and increase in inventory and lead times is perceptible. On the other hand, only few cases treated closed-loop supply chain. Indeed, it is a good initiative for implementing sustainability, and including more metrics like natural resources optimization. The advantage of closedloop supply chains is zero-waste and is based on recycling and the reuse of materials.

Finally, we can say that finding provide an overview on the research status on modeling approaches in Sustainable Resilient Supply Chain and offer insights into upcoming research studies. This research field is still growing and need to be studied in dept to meet challenges previously discussed. It can provide suitable solutions for practioners and have a positive impact on the real world.

In the future, this study can be extended to other modeling approaches and supply chain contexts. It can be conducted with the consideration of diverse environments and industries which offers better insights towards sustainability and resilience solutions.

7. FUTURE RESEARCH DIRECTIONS

Through findings and discussion, it can be stated that the research field of sustainable resilient supply chain is noteworthy and led us to point out research gaps and suggest future research directions summarized below:

- ✓ The literature combining simultaneously resilience and sustainability of supply chain should be strengthened. Only few reviews from our primary search deal with these concepts related to supply chain. Additionally, modeling approaches used need to be studied in depth and to be diversified in order to explore new methods that can bring out better results.
- ✓ The link between resilience and sustainability of supply chain should be studied deeper whether it is a win-win situation or trade-off between both concepts. Upcoming researches might take up some of the challenges to fill gaps in the emerging intersection of resilience and sustainability of supply chains.
- ✓ The complexity of real-life situations is an area that still need to be explored and studies. It brings out some innovative solutions using heuristic and meta-heuristic methods
- ✓ Some generic models can be tested in real world application to test their reliability.
- ✓ Uncertainty is a characteristic of resilience robust and possibilistic programming are approaches that still need to be studied in depth.
- ✓ Resilience is commonly focused on mastering uncertainty, while other strategies can be interesting to develop including more resiliency metrics in objective function. Moreover, to optimize to resilience part of supply chain. Another insight, concern the incorporation of a disruptive cost while modeling resilience in SC network.
- ✓ Considering resilience while modeling into each decision level can be an opportunity to make the supply chain more robust.
- ✓ The social dimension of sustainability is lesslooked and should be given more attention. More metrics in this sense need to be developed and can be included to objective functions.
- ✓ The link between supply chain problem type and modeling approaches is noteworthy. It can provide innovative solutions while designing the supply chain network.
- ✓ About the environmental impact, optimizing only one metric such as carbon emission does not cover the whole environmental impact. However, it is worthy to consider other metrics such as energy consumption, natural resources preservation, etc.
- ✓ The Economic dimension of sustainability is commonly limited to total cost minimization. Studying more solutions would be an opportunity for future contributions.
- ✓ Upcoming studies need to tackle more closely the resilience and sustainability bridge issues, especially while modeling. Scenario based model could be supplementary to assess the robustness of the supply chain network.
- ✓ There is a lack of strategies while modeling in the operational decision level of supply chains. It can be interesting completing the optimization by considering it.
- ✓ Closed-loop supply chains are a good initiative for implementing sustainability and can be an opportunity to optimize the use of natural resources.
- ✓ The scenario-based approach for resilience is very interesting for collaborative supply chains and for companies with common interests.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

8. LIMITATIONS

It is important to articulate our study's limitations to help researchers better situate themselves in relation to the topic. A primary limitation of the present work is related to the scope of the study, which is limited to papers treating sustainability and resilience of supply chains using mixed programming. The second limitation of the work concern the sample of the study, which concern 15 articles and remains a small sample size and that could be extended in upcoming reviews by conducting a generic study regarding all modeling approaches.

ACKNOWLEDGMENT

This review was conducted by the LASTIMI laboratory, Mohamed V University in Rabat, High School of Technology of SALE supported by ESITH Morocco. The authors are sincerely grateful to CELOG team and each person who have helped in any way to the accomplishment of this study.

CONFLICTS OF INTEREST

Authors declare no conflict of interest.

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Figure 11: Mind map of review categories

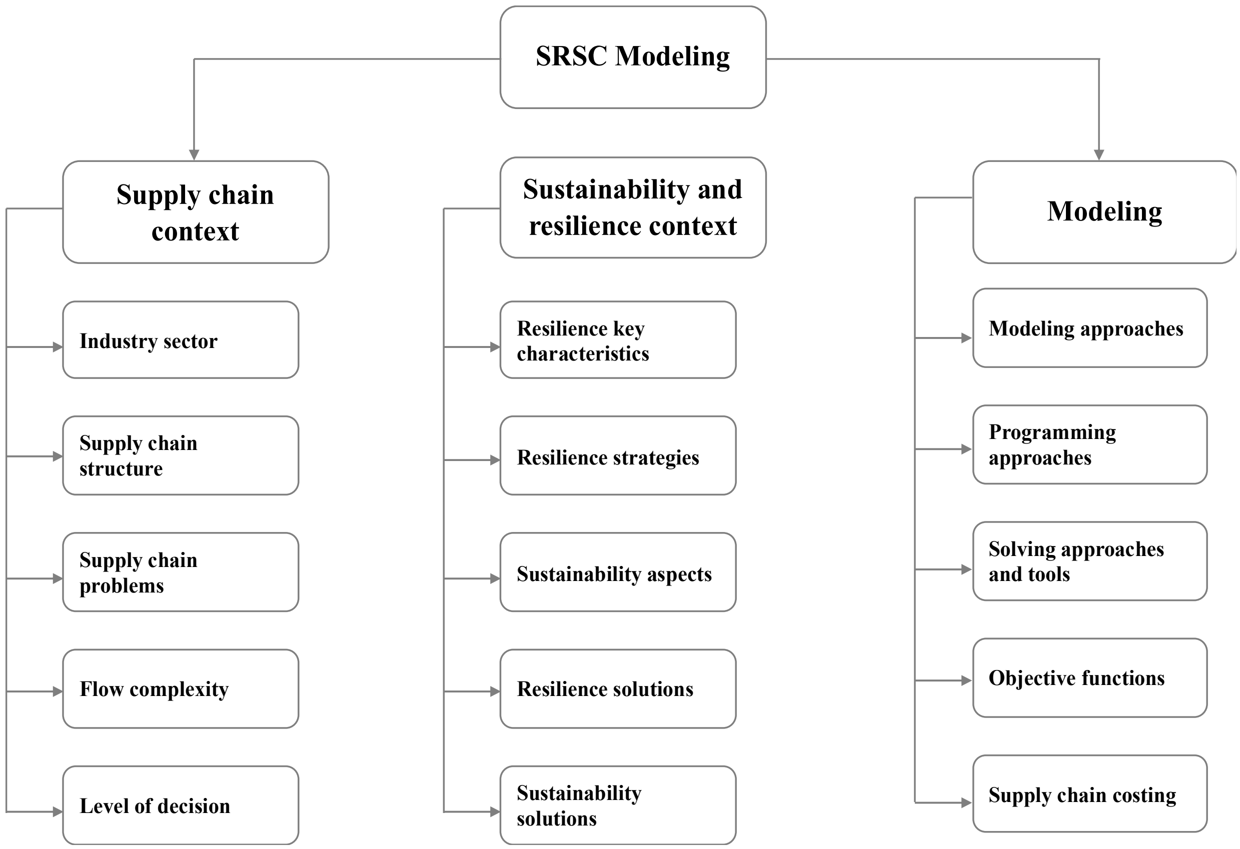

Table 9: categorization of Modeling

Publication reference	Modeling approaches	Multi-objective Bi-objective Single objective	Scenario based approach/ Multi stage programming	Programming approach	Simulation tools	Solving approach	Objective function
[76]	MILP	Bi-objective	YES underdisruption and without	Stochastic	NA	ε-constraint method	2 objective functions Max Z1 = profit maximisation Min Z2 = GHG emissions minimisation
[67]	MILP	Multi-objective	YES	Stochastic programming	NA	AUGMENCON2 method VSS	4 objective functions Min Z1= total cost Min Z2= environemental effect Max Z3= max job opportunities Min Z4= min delivery time
[63]	MFPFP	Multi-objective	NO	Possibilistic programming	NA	Utility function	4 objective functions Min Z1 = Min total Cost Max Z2 = Max Reliability Min Z3 = Min environmental effects Max Z4 = Max social responsability of the network
[70]	MILP	Multi-objective	YES	Stochastic programming	NEOS	LP-Metric	4 objective funtions Min Z1= Cost economic goal Min Z2= Environmental goal Min Z3= Cumulative energy demand goal Max Z4= Employment goal
[72]	MILP	Single objective	YES	Stochastic programming	LINGO	Chance constrained approach	1 objective function Min Z1= Total cost

[105]	MILP	Bi-objective	YES	Robust stochastic-possibilistic programming	CPLEX solver	Chance constrained approach	2 objective functions Min Z1= Min total cost without disruption scenarios Min Z2= Min total cost due to disruption scenarios
[109]	MINLP	Multi-objective	YES	Stochastic programming	LINGO	Chance constrained approach	3 objective functions Max Z1= Max product mix model Min Z2= Min total procurement cost Max Z3= Max profit (max ((Z1) - (Z2))
[62]	MILP	Multi-objective	YES	Stochastic Robust programming	NA	MCMGP-UF	4 objective functions Min Z1= Min total cost Min Z2= Min environmental impact Max Z3= Max social impact Min Z4= Min of the expected deviation of the SC responsiveness
[68]	MILP using fuzzy robust approach	Multi-objective	YES	Stochastic Robust programming	Developed Algorithm	FMOGP	3 objective functions Max Z1= Max total cost Min Z2= Min De-resiliency Max Z3= Max social responsability
[66]	MINLP Fuzzy multi-objective Programming 2 stage model	Multi-objective	YES	Stochastic & possibilistic	GAMS	Improved ε-constraint method Lagrangian relaxation method	4 objective functions Min Z1= Min total cost Max Z2= Max social aspects Min Z3= Min air pollution Max Z4= Max flexibility and network resilience
[106]	MILP Using Goal programming	Single objective	YES	Robust programming	LINDO API 8.0-solver	NA	1 objective function Min Z1= Min total cost

[65]	MILP	Multi-objective	YES	Stochastic programming	CPLEX solver	ε-constraint method	3 objective functions Max Z1= Max total economic cost Min Z2= Min Environmental impact Max Z3= Max Social Impact
[64]	MINLP & MILP *model linearized	Multi-objective	YES	Robust programming	CPLEX solver	LP metric	4 objective functions Min Z1= Min cost-economic goal Min Z2= Min environmental goal Min Z3= Min the consumed energy Max Z4= Max social impact
[99]	MILP	Multi-objective	NO	Stochastic & possibilistic programming	NA	Pareto-based lower bound method Meta-heuristic algorithm DVG	4 objective functions Min Z1= Min total cost in the network Max Z2= Max social impact of opening facilities Min Z3= Min total environmental impacts in the network Min Z4= Min non-resiliency of the network
[71]	MINLP	Single objective	YES	Stochastic programming	Monte carlo	Piece-wise Approximation algorithm	1 objective function Min Z1= Min Supply Chain total cost
[80]	MINLP	Single objective	YES	Stochastic programming	GAMS	Non-dominated sorting genetic algorithms (NSGA-II) Sub-population genetic algorithm (SPGA- II)	1 objective function Min Z1= Min total cost
[77]	MILP	Bi-objective	YES	NA	NA	Developped Algorithm	2 objective functions Min Z1= Min distance from the centroid C the area of interest Max Z2= Max reusability considering similarity and reconfigurabilit y t replca machine

[78]	MILP	Multi-objective	YES	Stochastic Robust programming	GAMS	Lagrangian relaxation method Constructive Heuristic (CH) algorithm	3 objective functions Min Z1= Min total cost Min Z2= Min environmental impact Max Z3= Max social impact
[79]	MILP 2 stage programming	Single objective	YES	Stochastic programming	Monte carlo	Sample Average Approximation Method	1 objective function Min Z= Min Total cost

Abbreviations:
Mixed Integer Linear Programming (MILP), Mixed Integer Non-Linear Programming (MINLP), Mixed Fuzzy Possibilistic Flexible Programming (MFPFP), Network-Enabled Optimization System (NEOS), Multi Choice Multi Goal Programming with Utility Function (MCMGP-UF), Fuzzy Multi-objective Goal programming (FMOGP), Improved version of the augmented ε-constraint method (AUGMENCON2), Not Applicable (NA).

Table 10: costing analysis

Publication reference	**Overall cost**			**Purchasing and procurement cost**						
	Total Cost	**Fixed cost**	**Variable cost**	**Product cost**	**Planning cost**	**Procurement cost**	**Purchasing cost**	**Emergency acquisition cost**	**Import/ Export cost**	**Ordering cost**
[76]							X			
[67]	X	X			X		X			X
[63]	X						X			
[70]	X	X	X							
[72]	X	X	X						X	
[105]	X	X							X	
[109]	X					X	X			X
[62]	X	X		X			X			
[68]	X				X					
[66]		X								
[106]	X		X	X						
[65]		X	X				X			
[64]	X	X	X							
[99]							X			
[71]	X	X	X	X				X		
[80]	X						X			
[77]	X									
[78]	X	X	X		X		X			
[79]	X	X			X					

Publication reference	Inventory cost			Production cost				
	Inventory cost	Handling cost	Holding cost	Production cost	Remanufacturing cost	Repair cost	Maintenance cost	*Harvesting cost
[76]				X				X
[67]		X	X	X				
[63]								
[70]								
[72]	X			X	X	X		
[105]	X			X				X
[109]	X		X					
[62]				X				
[68]							X	
[66]								
[106]	X		X					
[65]				X				
[64]								
[99]	X		X					
[71]	X		X					
[80]								
[77]				X	X			
[78]		X		X		X		
[79]	X							

Publication reference	Transportation cost		Set up cost					Warehousing cost	
	Transportation cost	Delay cost	Establishing/ facilities cost	Set up cost	Investment cost	Openning cost	Cost allocation	Processing cost	Operational cost
[76]	X				X				
[67]	X			X					
[63]			X						
[70]	X					X			
[72]	X								
[105]	X			X					
[109]	X								
[62]			X						
[68]			X		X				X
[66]	X		X			X		X	X

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[106]	X		X				X		
[65]	X		X			X			
[64]	X					X			
[99]	X		X						
[71]	X	X							
[80]	X								
[77]	X								
[78]	X		X			X			
[79]	X			X		X	X		

Publication reference	**Resiliency cost**			**Sustainability cost**		
	Demand uncertainty cost	**Unesiliency cost**	**Resiliency cost**	**CO2 emissions cost**	**Job opportunities creation cost**	**Energy consumption cost**
[76]				X		
[67]				X	X	
[63]				X	X	
[70]				X	X	X
[72]				X		
[105]				X		
[109]				X		
[62]				X	X	
[68]				X	X	
[66]				X	X	
[106]						
[65]				X	X	X
[64]				X	X	X
[99]		X	X	X	X	
[71]	X					
[80]						
[77]						
[78]						
[79]				X		

Publication reference	**Other cost**			
	Selling cost	**Reconfiguration cost**	**Salary cost**	**Capacity expansion cost**
[76]				
[67]				
[63]				
[70]			X	
[72]				
[105]				
[109]				
[62]				
[68]				
[66]				
[106]				
[65]				
[64]			X	
[99]	X			
[71]				
[80]				
[77]		X		
[78]				
[79]				X

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Table 11: categorization of Resilience and sustainability context

Publication reference	Resilience key characteristics	Resilience strategies	Sustainability aspects	Resilience solutions	Sustainability solutions
[76]	Robustness	Risk mitigation Activity restart SC stabilization	EV, EC	ENA	CR
[67]	Risk of Disruption, responsiveness, accessibility	Risk aversion Risk mitigation Stabilization Activity restart	EV,EC, SO	MS, BS, ES	CR, JO
[63]	Uncertainty, Risk of disruption	Risk aversion Risk mitigation	EV,EC, SO	BP	CR, JO, NR, IP
[70]	Risk of Disruption, Robustness	Risk aversion Risk mitigation Stabilization Activity restart	EV, EC, SO	RAV	CR, JO, EC
[72]	Risk of disruption, Uncertainty, Flexibility	Risk aversion Risk mitigation Stabilization	EC, EV	NA	CR
[105]	Uncertainty, Risk of disruption	Risk aversion Risk mitigation	EV, EC	FS	CR
[109]	Uncertainty, Risk of disruption	Risk aversion Risk mitigation	EV, EC	NA	CR
[62]	Uncertainty, Robustness, Responsiveness	Risk aversion Risk mitigation Stabilization Activity restart	EV, EC, SO	SL, MF, NCo, NCr, D, FC	CR, SF, JO
[68]	Uncertainty, Accessibility, Risk of disruption	Risk aversion Risk mitigation Stabilization Activity restart	EV, EC, SO	NA	CR, EDR, JO
[66]	Uncertainty, flexibility	Risk aversion Risk mitigation Stabilization	EV, EC, SO	NCo, FC	CR, JO
[106]	Uncertainty, Risk of Disruptions	Risk aversion Risk mitigation	EV, EC	NCo, FC	CR
[65]	Uncertainty, risk of disruption, Accessibility	Risk aversion Risk mitigation	EV, EC, SO	IS, MS, BS	CR, JO, NR, EC
[64]	Uncertainty, risk of disruption, flexibility, Robustness	Risk aversion Risk mitigation	EV, EC, SO	RA, CB	CR, JO, EC
[99]	Uncertainty	Risk mitigation	EV, EC, SO	NCr, NCo, FC, CDSL, NTA	CR, JO, EDR
[71]	Uncertainty, risk of disruption,	Risk aversion Risk mitigation	EV, EC	BS	CR
[80]	Risk of disruption Flexibility	Risk aversion Risk mitigation	EV, EC	IS, CB	CR
[77]	Flexibilty Accessibility Mitigation Risk of disruption	Risk mitigation Stabilization	EV, EC, SO	MR, C, R	CR, JO, EDR
[78]	Uncertainty, risk of disruption, Responsiveness	Risk aversion Risk mitigation	EV, EC, SO	MS, CB	CR, JO

[79]	Uncertainty, risk of disruption	Risk aversion Risk mitigation	EV, EC, SO	CB, C, CDSL	CR, AC

Abbreviations:
Environmental (EV), Economic (EC), Social (SO), Back up supplier (BS), Buffer capacity (BC), Multiple Sourcing (MS), Information Sharing (IS), Fortification of Supplier,(FS) Prepositionning Inventory (PI), Emergency stock (ES) or Salvage inventory, multi-feed stock (MFS), Backup Plan (BP), Risk Assessment measuring (RA), Capacity Building (CB), Risk aversion (RAV), Node Criticality (NCr), New Technology and the (L+1) th level /multiple Assignment (NTA), Flow Complexity (FC), Node Complexity (NCo), Density (D), Customer Demand Service Level (CDSL), Carbon Emission Reduction (CR), Job Opportunities Creation (JO), Dangerousness Exposure (DE), Reduction of consumption of natural ressources (NR), Reuse (R), Immigration Prevention (IP), Energy Consumption (EC), Safety (SF), Economic Development Rate (EDR), Unemployment Rate (UER), Service Level (SL), Maintaining Flows (MF), Collaboration (C), Machine Reconfiguration (MR), Not Applicable (NA).

Journal of Theoretical and Applied Information Technology
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ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 12: categorization of Supply Chain Context

Publication reference	SC problems	SC structure	Sector	Flow complexity	Level of decision
[76]	Location allocation	Upstream and downstream	Sugar Beet SC	Multi-echelon	Strategic, Tactical
[67]	Production distribution	Upstream & Downstream	NA	Multi-echelon	Strategic, Operational
[63]	Production distribution	Closedloop	Tire industry	Multi-echelon Multi-period	Strategic, Tactical
[70]	Production distribution	Closedloop	Car manufacturing industry	Multi-echelon	Strategic
[72]	Facility location & production and distribution	Closedloop	NA	Multi-period Multi-product	strategic
[105]	Capacity Location	Upstream	lignocellulosic bioethanol SC	Multi-echelon Multi-period	Strategic, Tactical
[109]	Production procurement	Upstream	NA	NA	Tactical
[62]	Production distribution	Upstream & Downstream	Water heater indutry	Multi-echelon Multi-product	Strategic
[68]	Location Allocation	Upstream & Downstream	Electricity industry	Multi-period Multi-echelon	Strategic, tactical
[66]	Location	Closedloop	NA	Multi-echelon Multi-period	Strategic, tactical
[106]	Location	Upstream & Downstream	Apparel industry	Multi-echelon	Strategic
[65]	Supplier selection	Closedloop	Tire Industry	Multi-echelon	Tactical
[64]	Production distribution	Closedloop	Car assembler industry	Multi-echelon	Strategic
[99]	Location allocation	Upstream & Downstream	Pharmaceutical SC	Multi-period Multi-echelon	Strategic, tactical
[71]	Operational and distribution planning problem	Downstream	Food SC (hyperlocal grocery)	Multi-product Multi-agent	Tactical
[80]	Production distribution	Closedloop	Petrochemical	Multi-echelon*	Operational
[77]	Production distribution	Upstream	NA	NA	Strategic
[78]	Location	Closedloop	Tire industry	Multi-echelon Multi-period	Strategic
[79]	Location allocation, inventory routing problem	Upstream & Downstream	NA	Multi-echelon	Strategic, Tactical, Operational