Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 107 (2022) 788–793

www.elsevier.com/locate/procedia

55th CIRP Conference on Manufacturing Systems

Adaptive model to increase resilience for emerging supply chains within the circular economy – “Zirkelmesser” an innovative case study

Jeff Mangers[a,*], Franz Wieck[b], Jana Nicolas[c], Peter Plapper[a], Manuel Löwer[b]

[a] *University of Luxembourg, 6 rue Coudenhove-Kalergi, L-1359 Luxembourg, Luxembourg*
[b] *University of Wuppertal, Gaußstraße 20, 42119 Wuppertal, Germany,*
[c] *Wuppertal Institute for Climate, Environment and Energy, Doeppersberg 19, 42103 Wuppertal, Germany*

* Corresponding author. Tel.: +352 46 66 44 5710. *E-mail address:* jeff.mangers@uni.lu

Abstract

Variations in quantity, quality and time availability of input materials pose a major risk to circular supply chains (CSC) and require new models for creating and evaluating adaptive and resilient CSC in the circular economy (CE). This can be achieved through consistent modelling of the overarching relationship between resource input- and output streams, without neglecting the associated risks.

The model proposed below consists of five components based on five resilience requirements for supply-chains (SCs). It provides a data-based recommended course of action for managers with a low entry-barrier. It consists of a CSC visualization, safety stock calculation, risk monitoring for each SC node, reporting logic, and a measurement catalogue. The inspiration for this model came from an innovative case study (“Zirkelmesser”) in the metal processing industry, where secondary products and materials are used to produce new products. Here, the problem of maintaining the resource supply arose and led to resilience issues. The mentioned case study serves as an application example for the model application and contributes to making emerging circular supply chains predictable and more controllable, thus increasing their resilience.

Keywords: Circular Economy; Supply-Chain; Value-Stream-Mapping (VSM); Resilience; Risk-Management; Product-Life-Cycle

1. Introduction

The Circular Economy (CE) is considered one of the core leavers to climate neutrality by decoupling economic growth and resource consumption [1]. The concept focuses on the systemic shift from a linear (take-make-waste) economy to one in which materials and products are reused and end-of-life disposal is prevented, e.g., through maintenance, and reuse [2].

CE requires cross-enterprise and within SCs thinking rather than within companies, making Supply Chain Management (SCM) a core enabler of CE [3]. Adopting new aspects in SCM requires attention to risks that need to be analysed and managed to avoid SC disruptions [4] and to increase SC resilience (SCRES) [5]. The comprehensive analysis of risks in CSC is still emerging in literature [4] and there is a need for approaches to assess circular supply chain risks on a practical, individual and holistic level [3], [4], [6]. This paper addresses future research directions identified in several literature reviews over the last two years, focusing on CSC measures, risks, and resilience in Circular Supply Chain Management (CSCM).

The model proposed in this paper aims to fill the identified gaps by combing five components based on the five resilience requirements for SCs from [6] and a risk analysis according to [4]. The first component is a value-stream-map (VSM) that visualizes the entire SC and merges all other components. The second component is a safety stock calculation, which is needed to determine the minimum quantities. It consists of three categories: SC-partners that act as material sources (their ‘waste’ is used as a new resource), SC-partners processing the product and an end-product. The remaining components are risk monitoring at each node of the SC, which is done via a spider-web diagram, a reporting system, and a measurement catalogue that is used to redesign the SC if required. The model itself is applied to an industrial use case where new knives are made entirely from waste products.

The remainder of the paper is structured as follows: Section 2 provides an overview of the current state of the art and the fundamentals needed to establish the new model, section 3 describes the methodology, section 4 outlines the results, and section 5 discusses the results and concludes.

2212-8271 © 2022 The Authors. Published by Elsevier B.V.

10.1016/j.procir.2022.05.063

2. **Related Work & Fundamentals**

For this paper, Geissdorfer's definition of the CE is reduced as follows: The CE is a regenerative system in which resource consumption and waste are minimised by closing material loops. This can be achieved through, amongst others, design, reuse, and refurbishment [2].

This section first illuminates the differences between linear and circular SCs and highlights the three main risks. Subsequently, the main literature in the field of CSCM is reviewed before discussing the basics of modelling, describing, and calculating risk and resilience in supply chains from the literature. This sub-step is necessary for research processes within applied research according to [7].

2.1 Motivation - Difference between Linear and Circular Supply Chains

To enable CE approaches on an industry level, well designed SCs are required [4]. Whilst there are many different SCM concepts like sustainable-SCM , green-SCM or circular-SCM, they are often used interchangeably [8] even though they are not interchangeable [3]. As [8] pointed out, the integration of CE aspects is still emerging in the area of SCM, especially from a conceptual viewpoint. Also, the above concepts do not apply the full CE approach [3]. This paper focuses on CSCMs and follows the proposed comprehensive definition of [8] (p. 884), in which "*the integration of circular thinking into the management of the supply chain [...]*" forms a crucial part.

In contrast to a linear SC, in a CSC input material is not produced on demand but derives as a secondary output, waste or by-product from another process [9]. This results in greater variations in material quantity, quality and time of availability [4], [10], [11] as in linear SCs, which are considered as the three main risks in the further course of the article. Possible variations regarding quality occur in parameters like, e.g., colour, composition or contamination, or geometry. This can trigger uncertainty [12] as it can affect production processes [10], e.g., the number of new products that can be produced. This match between input quantity, quality, and availability of inputs on the one hand, and the process requirements for the production of the new circular product on the other, is crucial for planning the CSC [9] and thus mitigating risk to increase resilience. This is a level of detail that has not been mentioned in the reviewed related work on CSC modelling. However, this demands for a data-based decision-support model, that allows for an assessment of the risk status of the CSC in question and offers measurements to increase the resilience of the CSC.

2.2 Identified Shortcomings within CSCM

In the last two years alone, many overarching literature reviews have been conducted on the topic of CSCM [3], [13]–[15]. In addition, the perspective on the manufacturing context of CSCM has already been analysed extensively [16]. Furthermore, many efforts have been made to scientifically describe the barriers and obstacles to the implementation of CSC measures [17]–[19] and to expand on the topics of risks [20], [21] and resilience [22], [23] of CSCM.

This paper addresses the future research directions identified in the previously described reviews, in particular [8] and [24]. Farooque [8] notes that CSC collaboration and coordination, design for circularity and product liabilities and producer's responsibility in particular need to be improved to advance CSCM. We summarise these topics as *product & organisational measures* for this paper. In their overview, Lahane [24] presents in particular the following problems and future directions for action: Risk factors and solutions, mathematical description and simulation, and a model for risk management and management decision-making. We summarise this under the term *risk & modelling*.

These two main concepts for improving the CSC – i) product & organisational measures and ii) risk & modelling - are explored through the presented case study.

2.3 Modelling - Describing, and Calculating Risk and Resilience for Supply Chains

A comprehensive overview of the different objectives and simulation tools for describing and calculating SCs is given by [25]. In their investigation, they divide the different approaches according to 1) objectives, 2) processes, and 3) morphology. They conclude that, especially in the case of independent firms, information sharing becomes a critical barrier, as each independent actor is usually unwilling to share its production data (e.g., production capacity, production costs, etc.) with the other "nodes". [26] propose a supply-chain value stream mapping (SCVSM) tool to thoroughly understand competitive priorities of volume and delivery for any SC in organisations, similar to [27] who added environmental aspects. Due to the increasingly networked and digitalised SC components, data-based approaches are a promising topic for the future. On the one hand, Big Data and IoT offer new data fundamentals, but on the other hand, they also pose new challenges to SC modelling, especially for live data [28]. Other studies on operational resilience deal with disruption absorption and recovery capacity [29]. To analyse SCMs, three analytical techniques are used: descriptive, predictive, prescriptive [30], whereas this paper's approach is a hybrid, a combination of descriptive (using VSM) and predictive (product-specific unit count calculation based on average unit counts).

Concerning the description and calculation of risk and resilience in SCs, [6] presents a detailed overview. In addition, [31] describe risk factors for SCs in great detail, whereas [32] discusses SC risk management, regarding maturity models (MM). From a more circular point of view, [4] lists risks like material delay, material and product quality, machine maintenance and transparent processes. Especially the quality aspect gets a new perspective because in a CSC the supplies are mainly by-products or remains from other products and processes. [33] reviews the SC risks regarding CE using Industry 4.0, in which the design-related problem for circular products is highlighted. [34] evaluates and ranks solutions to mitigate CSC risks, which are machine and equipment failures, gatekeeping design, delay deliveries, information security, standards & certifications, and cannibalization.

Our approach aims to determine the resilience of physical products, which makes it possible to identify critical influencing variables and provides the basis for making risks calculable in our model. According to [6], five strategies to improve the resilience of physical capitals exist, which are used as goals for the hereinafter presented model. The link towards the different components is made in the next chapter.

To summarize chapter 2, in contrast to the linear economy in CE, material quantities can no longer simply be ordered whenever there is a need, but there is a specific time when a certain quantity with a corresponding quality is available.

3. Methodology

The following four-step methodology is inspired by Ulrich's methodology for applied research [7]:

1) Determining CE resilience problem within SC
2) Literature review
3) Model development
4) Data capturing & testing

The first step is based on a case study of a CE concept called 'Zirkelmesser'. After a successful launch, the question arises how to ensure a reliable supply of the circular resources to keep production running. Since the input resources for the final product are by-products or leftovers from other production processes, additional aspects (e.g., available quantity, quality, and time) must be considered to ensure a reliable supply. This resulted in the need for a new model to outline, predict and ensure the required resilience. The second step consists of a comprehensive review of already established concepts in the context of SCRES and the needs of CSCs. For physical resources, five resilience requirements for SCs were defined in [6], which are used as a conceptual framework for the developed model in the third step, outlined in Table 1.

Table 1. The link between resilience requirements and the model

Nr	Resilience requirement [6]	Model component
1	Increase visibility	C-VSM for increased SC resilience
2	Safety stock	Safety stock calculation
3	Risk monitoring for each node	MM based risk monitoring diagram
4	Predictive tool	Reporting system logic
5	Redesign the SC	Measurement catalogue

The last step concerns the data capturing to complete the model and test its applicability. This step is performed as an iteration with the model development phase.

4. Results

The newly developed model consists of five components (see Table 1). To prevent individual components from not being able to communicate adequately with each other, they are interconnected within the VSM model (see Figure 1), except for the last component. The functioning of the individual components and the overall model is explained below.

4.1 C-VSM for Increased SC Resilience

The first component, VSM, is a commonly known lean method used to visualize the current state of product and information flows within organizations [35]. Generally, it is used to seek for weaknesses and improve process flows, while in this case we use it to outline the results of the developed predictive model. As a framework we use the C-VSM [36], which is adapted to the needs of CE. The macro-level view allows the visualization of the entire SC. Along the right site, a value ladder (based on the 9R-framework [37]) is included to assess the CE value of the product throughout its PLC. This is an interesting feature, to compare the 'Zirkelmesser' (value: R7-Repurpose) with a traditional linear knife (value: 0-linear).

The different companies are visualized by three different boxes, with information and relations adapted to the real case. The companies paper-cutter (produces different kinds of papers and uses circular knives for cutting) and plastic-parts (production of products with plastic shells and components) are represented as supplier companies, since they are the sources of material for the final product. The companies blade-lasering (subcontractor, cutting the blades out of the circular knives) and the handle injection moulding (subcontractor, moulding plastic handles for the blades, using recycled material as input) are presented as normal processes, since they operate as processing or subcontracting companies. The knife-grinding company is presented as a customer company, since it is the original equipment manufacturer (OEM) of this SC. Depending on the type of company, different information is displayed within the company-boxes. The supplier companies have a prediction box (first box), that acts as a notification box (component 4) when a potential risk is detected. Logic checks if the underlying availability or risk box exceeds the respective limit. The underlying availability box indicates the required quantity of the available sourcing quantity and represents component 2. The third box, risk, is a sum of all the risks visualised by the spider-web diagram (last box) and represents component 3. In the other boxes, some more general parameters are givin, such as weight per functional unit, quantity available at source, quantity takt and safety margin. The processing company boxes are structured like the C-VSM boxes. Some specific parameters like minimum order quantity for SCs in general (MOQG), minimum order quantity for the respective company (MOQC) and the delivered quantity (QD) are listed here. The customer boxes again have a prediction, an availability, and a risk box. The trucks indicate the load quantity (W) and the distance to be driven (D). The information flows are divided into two sections. The green dashed lines indicate who gives the design specifications and who receives them, while the blue dashed lines indicate the same for the recovering system.

By integrating the VSM, the model satisfies the first requirement from [6] by increasing the visibility of the company's interactions within the SC, visualized in Figure 1.

4.2 Safety Stock Calculation

In the second component, the necessary safety stocks and the minimum quantities for the SC are calculated. Especially the lower limit is an important limit for production. That is, at what quantity is the effort justified (e.g., machine set-up time, machine parameters, staff training, etc.). This question is answered for each actor in the entire value chain and applied to the entire SC. In this way, the capacity of the entire SC is determined. The calculation model is based on the requirements of CE, on the fact that potential waste is generated at an actor (material source), which is further processed via different process steps (processes) to a final product (market). This three-role model can be used to determine the critical material sources, process steps, minimum quantities, and other characteristics for a CSC. The necessary key figures and values are shown in Table 2.

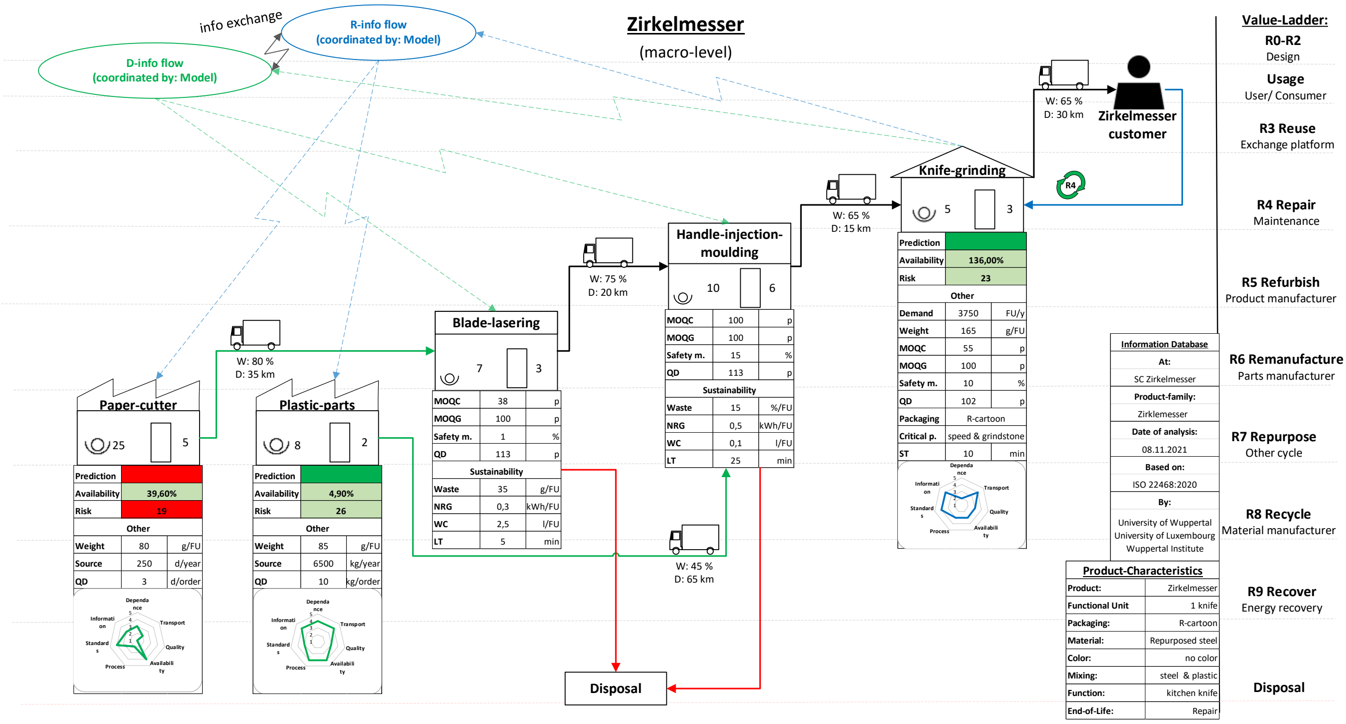

Figure 1. C-VSM Zirkelmesser, macro-level

Table 2 represents the case for exactly one material source, one production process and one product and consists of indicators to be determined (upper area) and indicators and performance measures to be calculated (left column).

In the upper area, the available material quantities are collected. In addition to the quantities, the values entered also include safety margins (e.g., scrap rate during production, material wastage during machine start-up, etc.) and other limiting factors, such as geometric dimensions. The last parameter to be determined is the product composition, which considers the different materials and components of the product. This composition is later used to determine the individual material quantities in relation to the final product. The procedure to complete the table consists of 4-steps:

1. Minimum number of units,
2. Material quantities for the units,
3. Capacity utilization and
4. Required quantities to be supplied

Table 2. The logic behind the calculation model

Product composition [PC_n]	**Material source [MS_n]**	**Process [P_n]**	**Market & Product [M_n]**
FU	Amount of material available [a]	Minimum quantity for the process cycle [a]	Product request / customer demand
Material 1	Other factors influencing the (usable) material quantity	Other factors influencing the quantity in production	-
Material 2	Extended safety material quantity	Extended safety material quantity	-
Calculated indicators and performance metrics [b]			
Minimum number of units	-	N/A	-
Material quantities for the units	N/A	N/A	-
Capacity utilization	N/A	N/A	-
Required quantities to be supplied [c]	N/A	N/A	N/A

[a] Stakeholder specific unit (FU) [b] For each material [c] Same time period

The minimum quantity is determined in the various processing companies and considers the necessary batch size to start a production. This limit value is now used to determine the necessary material quantities for each station, considering the respective product composition. The next step is to determine the capacity utilisation for the material source and the processes. For CE, the characteristic value is particularly relevant for the material source, as it quantifies the utilization rate of the source. In the last step, the required quantities to be supplied in a given time frame are determined for everyone in the entire SC. This value is calculated considering the extended safety material quantity and the minimum number of units of the total SC to meet customer demand. This value enables all actors to align their internal processes with the process SC, identify risks early, communicate and ensure material requirements, and calculate costs. The numerical values adopted in the VSM are marked accordingly in Table 3.

For the case study, the model is adapted and calculated as follows: 2 different materials (steel and plastic) coming from 2 material sources (paper-cutter and plastic-parts), 3 processes (blade-lasering, injection-moulding, knife-grinding) and 1 final product - the Zirkelmesser (see Table 3).

4.3 Maturity Model based Risk Monitoring Diagram

The third component deals with the requirements for monitoring the risk of the individual nodes. This is illustrated by a spider-web diagram (see Figure 1), which is included in the VSM for the suppliers and customer companies. It is based on the idea of MMs and includes seven different risk categories. The categories are dependence, transport, quality, availability, process, standards, and information. They are derived from the literature review and are reduced to meet the needs of this case study. For each of the categories, a question is asked, and the answer is a risk evaluation between extremely high (value 1) and extremely low (value 5), according to a Likert scale. The higher the value, the lower the risk and thus the better the assessment. The spider-web diagram shows which categories represent the greatest risk. To simplify risk prediction, a threshold value has been added that lights up when the sum of the individual risks falls below a certain value, indicating an increased risk.

Table 3. The calculation table from the case-study

Product composition [PC_n]		Material source [MS_n]				Process [P_n]						Market & Product [M_n]	
Zirkelmesser		**Paper-Cutter**	values	**Plastic-Parts**	values	**Blade-Lasering**	values	**Handle-Injection-Molding**	values	**Knife-Grinding**	values	**Zirkelmesser-Customer**	values
Functional Unit [FU]	1	Material type [Metallround]	Steel	Material type	Plastic	Minimum quantity for the process cycle [a] [FU]	38	Minimum quantity for the process cycle [a] [FU]	100	Minimum quantity for the process cycle [a] [FU]	50	customer demand [FU] **(VSM: Demand)**	3750
Steel [kg]	0,08	Amount of material available [a] [pcs per Year] **(VSM: Source)**	250	Amount of material available [a] **(VSM: Soure)**	6500	Other factors influencing the (usable) material quantity:		Other factors influencing the (usable) material quantity:		Other factors influencing the (usable) material quantity:		Amount of material available [a] [pcs per Year] --> 50 runs per year	0
Plastic [kg]	0,085	Other factors influencing the (usable) material quantity:		Other factors influencing the (usable) material quantity		Product geometry [1] diameter Condition: d1< d < d2 | Estimated impact in [%] **(VSM: Safety m.)**	1	machine in operation, sprues, etc. [%] **(VSM: Safety m.)**	15	Product geometry - [2] thickness Condition: s < 2mm | Estimated impact in [%] **(VSM: Safety m.)**	10	- not considered -	
		Product geometry - [1] diameter & [2] thickness		- not considered -		Extended safety material quantity	38	Extended safety material quantity [FU]	115	Extended safety material quantity [FU]	55	- not considered -	
		FU per provided piece	38										
Calculated indicators and performance metrics [b]													
Minimum number of units		-				Minimum number of units **(VSM: MOQC)**	38	Minimum number of units **(VSM: MOQC & MOQG)**	**100**	Minimum number of units **(VSM: MOQC)**	55	- not considered -	
Material quantities per process run		Worn Metallround [pcs] [rounded] **(VSM: QD)**	3	Unused Plastic [kg] [rounded] [based on Blade-Lasering!] **(VSM: QD)**	10	Knife-Conturs [pcs.] **(VSM: QD)**	113	Knife-with-Handles [pcs.] **(VSM: QD)**	113	Sharp Knife-with-Handles [pcs.] **(VSM: QD)**	102	- not considered -	
Material quantities per year		Worn Metallround [pcs] [rounded]	99	Unused Plastic [kg]	318,8	- not considered -		- not considered -				- not considered -	
Capacity utilization		[%] [per year] **(VSM: Availability)**	39,6	[%] [per year] **(VSM: Availability)**	4,90	- not considered -		- not considered -		[%] [per year] **(VSM: Availability)**	0,00	- not considered -	
Required quantities to be supplied [c]		Worn Metallround [pcs / per month]	9	Plastic waste [kg / per month]	27	Knife-Conturs [pcs. / per month]	312,5	Knife-with-Handles [pcs. / per month]	312,5	Sharp Knife-with-Handles [pcs. / per month]	312,5	Product Sales [pcs. / per month]	312,5

[a] Stakeholder specific unit (FU) [b] For each material [c] Same time period

4.4 Reporting System Logic

The fourth component acts as the logic of the reporting system and has already been partially explained before. It checks whether the result of components 2 or 3 is critical and displays this as green (no critical value) or red (at least one value is critical) in the first field of the suppliers or customer company box in the VSM. The logic behind the prediction tool is thus kept quite simple and builds on the two previous components.

4.5 Measurement Catalogue

The last component is a measurement catalogue. It guides the user through the steps required to redesign or adapt the SC to mitigate the risks indicated by the reporting system. It is divided into three categories:

1) Material-concerns
2) Process-concerns
3) Actor-concerns

The material category includes issues regarding quantity, quality, and time of availability. If the available quantity is too low, the supplier of the product in question can be contacted to find out if they want to participate in the SC. If there are problems with the quality of the resources supplied, it is necessary to determine where these problems are coming from. Solutions could include changes to the previous service life or an increase in the safety margin. Resolving issues with varying or unknown availability times are critical, as information sharing between companies needs to be improved. For the second category, the simplified MM should be reviewed first. Due to the more imprecise use of materials, production processes may need to be completely rethought to meet the new conditions. If the circular knives are too resistant for the conventional grindstones, radical adjustments may be necessary. The last category relates to SC-actors, where the basis for greater agility must be differentiated. There needs to be a list of regional and complementary companies in the same field to mitigate potential issues. Since similar SCs are currently more of a one-off affair, most active companies see their participation as a side-line rather than their core business, which increases the importance of preparation.

The next chapter discusses and challenges the results obtained and concludes with an outlook on future extensions.

5. **Discussion and Conclusion**

By developing and combining 1) VSM for visualisation, 2) a calculation model to determine necessary material capacities and safety stocks, 3) risk monitoring based on several risk factors, 4) an early warning system and, 5) a catalogue of measures to solve existing problems in the SC by redesigning the SC., a resilience assessment and improvement model for CSCs was created. This model provides a data-based recommended action for managers at a low entry-barrier. The cross-company extended VSM model enables visualization and consistency of information, leading to CE capability improvement. Safety stock calculation includes new aspects, as quantity and quality determination within a CSC is more volatile than in a linear one. The risk monitoring and reporting components visualize potential weaknesses in the design of the CSC. The last component, the measurement catalogue is easy to use and helps guide the user through the necessary designing steps. The literature review identified shortcomings for CSCM within the missing collaboration and coordination between SC-partners and the need for solutions that combine risk factors through mathematical descriptions by providing support for decision making. By summarizing the aforementioned issues, this paper makes a constructive, application-oriented contribution in the field of CSCM, particularly with respect to i) product & organisational measures and ii) risk & modelling.

The outlook is divided into three categories. The first concerns data entry with insufficient (automated) updating of data and aspects of confidentiality. The confidentiality issue could be solved by adding an additional layer on top of the VSM that would allow the overall calculations to be performed while displaying only the information specific to each stakeholder. The second category deals with possible add-ons, in the form of further sustainability [38] and financial parameters or further focus on on-time delivery or availability of the materials. The third category refers to the integration of an automatic determination of an ideal status of the CSC (based on artificial intelligence and machine learning). The model of this work holds further potential for extension and refinements to reflect the complexity of SC modelling in the CE.

All these points reduce the risks and show how CE can be made describable, calculable, and predictable. This reduces the complexity of the overall system, which is also caused by the heterogeneity of the stakeholders. The 'Zirkelmesser' was able to demonstrate this in a very convincing first approach with practical relevance. Moreover, this study represents a particularly strong added value in the context of CSC modelling. Since a distinction is explicitly made here between material source and further processing, the associated characteristic values can be consistently recorded and processed. This distinction, with a focus on variations in quantity, quality, and time availability of input materials, makes it possible to explicitly determine the context and potential of industrial waste for subsequent manufacturing processes and products.

Author Contribution

Conceptualization, Methodology, Validation Writing - Original Draft, Writing - Review & Editing, Visualization: JM, FW, JN; Resources: FW; Supervision: PP, ML

Acknowledgements

This research was funded by Di-Plast (Digital Circular Economy for the Plastics Industry), and by European Regional Development Fund (ERDF) as part of the project "Regional resource management using the example of the metalworking industry in the Bergisch Region". The authors would like to thank the participating companies and others involved in the implementation of the Zirkelmesser (www.zirkelmesser.de).

References

[1] European Commission, "A new Circular Economy Action Plan For a cleaner and more competitive Europe," Brussels, 2020.

[2] M. Geissdoerfer, P. Savaget, N. M. P. Bocken, and E. J. Hultink, "The Circular Economy – A new sustainability paradigm?," *J. Clean. Prod.*, vol. 143, pp. 757–768, 2017, doi: 10.1016/j.jclepro.2016.12.048.

[3] B. T. Hazen, I. Russo, I. Confente, and D. Pellathy, "Supply chain management for circular economy: conceptual framework and research agenda," *Int. J. Logist. Manag.*, vol. 32, no. 2, pp. 510–537, 2021, doi: 10.1108/IJLM-12-2019-0332.

[4] M. Ethirajan, T. Arasu M, J. Kandasamy, V. K.E.K, S. P. Nadeem, and A. Kumar, "Analysing the risks of adopting circular economy initiatives in manufacturing supply chains," *Bus. Strateg. Environ.*, vol. 30, no. 1, pp. 204–236, 2021, doi: 10.1002/bse.2617.

[5] N. O. Hohenstein, E. Feise, E. Hartmann, and L. Giunipero, "Research on the phenomenon of supply chain resilience: A systematic review and paths for further investigation," *Int. J. Phys. Distrib. Logist. Manag.*, vol. 45, no. 2005, pp. 90–117, 2015, doi: 10.1108/IJPDLM-05-2013-0128.

[6] M. Pournader, K. Rotaru, A. P. Kach, and S. H. Razavi Hajiagha, "An analytical model for system-wide and tier-specific assessment of resilience to supply chain risks," *Supply Chain Manag.*, vol. 21, no. 5, pp. 589–609, 2016, doi: 10.1108/SCM-11-2015-0430.

[7] H. Ulrich, *Management*, Schriftrei. Stuttgart, 1984.

[8] M. Farooque, A. Zhang, M. Thürer, T. Qu, and D. Huisingh, "Circular supply chain management: A definition and structured literature review," *J. Clean. Prod.*, vol. 228, pp. 882–900, 2019, doi: 10.1016/j.jclepro.2019.04.303.

[9] D. M. Yazan, V. A. Romano, and V. Albino, "The design of industrial symbiosis: An input-output approach," *J. Clean. Prod.*, vol. 129, pp. 537–547, 2016, doi: 10.1016/j.jclepro.2016.03.160.

[10] P. Bansal and B. Mcknight, "Looking forward, pushing back and peering sideways: Analyzing the sustainability of industrial symbiosis," *J. Supply Chain Manag.*, vol. 45, no. 4, pp. 26–37, 2009, doi: 10.1111/j.1745-493X.2009.03174.x.

[11] F. Acerbi, D. A. Forterre, and M. Taisch, "Role of artificial intelligence in circular manufacturing: A systematic literature review," *IFAC-PapersOnLine*, vol. 54, no. 1, pp. 367–372, 2021, doi: 10.1016/j.ifacol.2021.08.040.

[12] D. M. Yazan and L. Fraccascia, "Sustainable operations of industrial symbiosis: an enterprise input-output model integrated by agent-based simulation," *Int. J. Prod. Res.*, vol. 58, no. 2, pp. 392–414, 2020, doi: 10.1080/00207543.2019.1590660.

[13] J. Cerqueira-Streit, G. Endo, P. Guarnieri, and L. Batista, "Sustainable Supply Chain Management in the Route for a Circular Economy: An Integrative Literature Review," *Logistics*, vol. 5, no. 4, p. 81, 2021, doi: 10.3390/logistics5040081.

[14] R. González-Sánchez, D. Settembre-Blundo, A. M. Ferrari, and F. E. García-Muiña, "Main dimensions in the building of the circular supply chain: A literature review," *Sustain.*, vol. 12, no. 6, pp. 1–25, 2020, doi: 10.3390/su12062459.

[15] P. Lengyel *et al.*, "Development of the Concept of Circular Supply Chain Management—A Systematic Review," *Processes*, vol. 9, no. 10, p. 1740, 2021, doi: 10.3390/pr9101740.

[16] F. Acerbi, C. Sassanelli, S. Terzi, and M. Taisch, "A Systematic Literature Review on Data and Information Required for Circular Manufacturing Strategies Adoption," *Sustainability*, vol. 13, no. 4, p. 2047, 2021, doi: 10.3390/su13042047.

[17] M. Chhimwal, S. Agrawal, and G. Kumar, "Challenges in the implementation of circular economy in manufacturing industry," *J. Model. Manag.*, vol. ahead-of-p, no. ahead-of-print, 2021, doi: 10.1108/JM2-07-2020-0194.

[18] J. Grafström and S. Aasma, "Breaking circular economy barriers," *J. Clean. Prod.*, vol. 292, 2021, doi: 10.1016/j.jclepro.2021.126002.

[19] J. Tan, F. J. Tan, and S. Ramakrishna, "Transitioning to a Circular Economy: A Systematic Review of Its Drivers and Barriers," *Sustainability*, vol. 14, no. 3, p. 1757, 2022, doi: 10.3390/su14031757.

[20] M. Chhimwal, S. Agrawal, and G. Kumar, "Measuring Circular Supply Chain Risk: A Bayesian Network Methodology," *Sustainability*, vol. 13, no. 15, p. 8448, 2021, doi: 10.3390/su13158448.

[21] E. F. Dulia, S. M. Ali, M. Garshasbi, and G. Kabir, "Admitting risks towards circular economy practices and strategies: An empirical test from supply chain perspective," *J. Clean. Prod.*, vol. 317, p. 128420, 2021, doi: 10.1016/j.jclepro.2021.128420.

[22] S. Alonso-Muñoz, R. González-Sánchez, C. Siligardi, and F. E. García-Muiña, "New Circular Networks in Resilient Supply Chains: An External Capital Perspective," *Sustainability*, vol. 13, no. 11, p. 6130, 2021, doi: 10.3390/su13116130.

[23] A. Shishodia, R. Sharma, R. Rajesh, and Z. H. Munim, "Supply chain resilience: A review, conceptual framework and future research," *Int. J. Logist. Manag.*, 2021, doi: 10.1108/IJLM-03-2021-0169.

[24] S. Lahane, R. Kant, and R. Shankar, "Circular supply chain management: A state-of-art review and future opportunities," *J. Clean. Prod.*, vol. 258, 2020, doi: 10.1016/j.jclepro.2020.120859.

[25] S. Terzi and C. S., "Simulation in the supply chain context: a survey," *Comput. Ind.*, vol. Vol. 53, pp. 3–16, 2004.

[26] M. F. Suarez-Barraza, J. Miguel-Davila, and C. F. Vasquez-García, "Supply chain value stream mapping: a new tool of operation management," *Int. J. Qual. Reliab. Manag.*, vol. 33, no. 4, pp. 518–534, 2016, doi: 10.1108/IJQRM-11-2014-0171.

[27] F. A. Sultan, S. Routroy, and M. Thakur, "A simulation-based performance investigation of downstream operations in the Indian Surimi Supply Chain using environmental value stream mapping," *J. Clean. Prod.*, vol. 286, p. 125389, 2021, doi: 10.1016/j.jclepro.2020.125389.

[28] A. P and M. M. Patil, "A Review on Data Analytics for Supply Chain Management: A Case study," *Int. J. Inf. Eng. Electron. Bus.*, vol. 10, no. 5, pp. 30–39, 2018, doi: 10.5815/ijieeb.2018.05.05.

[29] D. Essuman, N. Boso, and J. Annan, "Operational resilience, disruption, and efficiency: Conceptual and empirical analyses," *Int. J. Prod. Econ.*, vol. 229, no. June 2019, p. 107762, 2020, doi: 10.1016/j.ijpe.2020.107762.

[30] G. C. Souza, "Supply chain analytics," *Bus. Horiz.*, vol. 57, no. 5, pp. 595–605, 2014, doi: 10.1016/j.bushor.2014.06.004.

[31] S. Rao and T. J. Goldsby, "Supply chain risks: A review and typology," *Int. J. Logist. Manag.*, vol. 20, no. 1, pp. 97–123, 2009, doi: 10.1108/09574090910954864.

[32] I. S. Cavalcante de Souza Feitosa, L. C. Ribeiro Carpinetti, and A. T. de Almeida-Filho, "A supply chain risk management maturity model and a multi-criteria classification approach," *Benchmarking*, vol. 28, no. 9, pp. 2636–2655, 2021, doi: 10.1108/BIJ-09-2020-0487.

[33] Y. Kazancoglu, Y. D. Ozkan-Ozen, M. Sagnak, I. Kazancoglu, and M. Dora, "Framework for a sustainable supply chain to overcome risks in transition to a circular economy through Industry 4.0," *Prod. Plan. Control*, 2021, doi: 10.1080/09537287.2021.1980910.

[34] S. Lahane and R. Kant, "Evaluation and ranking of solutions to mitigate circular supply chain risks," *Sustain. Prod. Consum.*, vol. 27, pp. 753–773, 2021, doi: 10.1016/j.spc.2021.01.034.

[35] ISO 22468:2020, "Value stream management (VSM)."

[36] J. Mangers, M. Minoufekr, and P. Plapper, *Value Stream Mapping (VSM) to Evaluate and Visualize Interrelated Process-Chains Regarding Circular Economy*, vol. 633 IFIP. Springer International Publishing, 2021.

[37] J. Kirchherr, D. Reike, and M. Hekkert, "Conceptualizing the circular economy: An analysis of 114 definitions," *Resour. Conserv. Recycl.*, vol. 127, no. April, pp. 221–232, 2017, doi: 10.1016/j.resconrec.2017.09.005.

[38] J. K. Y. Lee *et al.*, "Sustainability-Oriented Application of Value Stream Mapping: A Review and Classification," *IEEE Access*, vol. 9, no. May, pp. 68414–68434, 2021, doi: 10.1109/ACCESS.2021.3077570.