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Supply Chains modelling with Agent Based Simulation: a methodological exploration of agent types and their interactions

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Abstract

This paper elaborates on an earlier review, which assessed the benefits of simulation in the design of sustainable supply chains. Specifically, the analysis is limited to the subset of contributions dealing with Agent Based Simulation (ABS) and aims to understand: (i) how much this simulation type is used, (ii) for which kind of supply chain it is mostly adopted, and (iii) whether there are recurring patterns in the implemented agents. Our initial assumption was that ABS was frequently used to model non-linear and/or circular supply chains, but quite surprisingly, this supposition has not been validated by the outcomes of our analysis. What emerges, in fact, is the limited use of ABS, which does not show a noticeable upward trend even in recent years. Not only the use of ABS is scarce, but many of the models we reviewed cannot be classified as "pure ABS", as they could be easily reproduced with a classic "discrete events" approach. These issues seem to indicate that ABS is not yet mastered by most of the scientific community operating in the field of supply chain management. Therefore, the paper ends by outlining possible approaches to foster the use of ABS as a valid tool to reproduce the behaviour and common influences of supply chain agents.

Keywords: Agent Based Simulation; Supply Chain; Systematic Review, Sustainability.

1. Introduction

The design and management of an effective and resilient Supply Chain (SC) has always been considered a fundamental key to achieve competitiveness, in a rapidly evolving marketplace (Kale, 2016). Nowadays, these aspects have become even more relevant due to the ongoing climate change and, consequently, to end customers that are becoming more and more aware of their environmental footprint. In this regard, supply chain sustainability has emerged as a very urgent and promising field of research, with relevant implications both in the academia and in the industry (Matopoulos et al., 2015).

To design, plan and optimize a SC, based on economic, environmental, and social requirements, several tools are available. Anyhow, since SC are complex and adaptive systems (Choi et al., 2001), difficult to be comprehensively described through a mathematical model, among them, simulation plays a key role, as it allows assessing the performance of a system in a relatively quick and inexpensive way, without the need of the full state-transition matrix, governing the dynamic of the system. As well known, three simulation approaches exist, namely Discrete-Event Simulation (DES), Agent-Based Simulation (ABS) and System Dynamics (SD). Briefly, DES is a modelling technique used to understand and analyse complex systems where events, driving the system's behaviour, occur at distinct points in time. DES models focus on the chronological sequence of these events and on the interactions among them, allowing for the examination of system performance, resource allocation, and process optimization. ABS is a modelling approach that simulates the actions and interactions of autonomous agents within a given environment. Agents are entities with individual characteristics, behaviours, and decision-making capabilities, which can interact with each other and their environment according to predefined rules. This approach is particularly useful for modelling systems with heterogeneity, decentralization, and non-linear interactions, such as social networks, ecological systems, and market economies. Lastly, SD is a methodology for modelling the behaviour of complex systems over time, emphasizing the feedback loops and interdependencies among system components. More precisely, it represents systems as interconnected stacks, flows, and feedback loops. These models enable the exploration of dynamic behaviour, such as growth, decay, oscillation, and stability, facilitating the understanding of system behaviour under various boundary conditions. There is no doubt that, due to their unquestionable merits, DES and ABS approaches are the most used ones especially for SC modelling and analysis. Conversely, the use of SD is rather rare, if not in combination with DES and/or ABS in the so-called hybrid simulation models.

The present paper originates from one of our previous works (Moroni et al., 2024), in which we performed a structured literature review (conforming to the PRISMA model), to identify a comprehensive set of papers published in the last decade, which use ABS or DES simulation approaches, either in a stand-alone or in a hybrid way, to design and/or to optimize sustainable SCs. Selected works were classified in terms of: (i) used simulation framework (i.e., ABS, DES or hybrid), (ii) supply chain structure, as in the definition given by (Guide & Van Wassenhove, 2006; Weetman, 2020) (i.e., linear, open loop same sector, open loop cross sector, closed loop) and (iii) supply chain complexity as suggested by (Gardiner & Reefke, 2019) (i.e., length and width, that is numbers of echelon and echelons' maximum span).

In this work, we deepened the analysis focusing on the papers dealing with ABS as it is the only simulation approach that enables the study of emergent phenomena arising from the interactions of individual agents, offering insights into complex systems' dynamics and collective behaviours. Our believe, in fact, is that a clear understanding of citizens' behaviours and their responses to incentives, policies, and other interventions is crucial for designing a sustainable SC. Citizens play a pivotal role as consumers, producers, and decision-makers within the SC ecosystem. Their choices and actions influence demand patterns, production processes, and the overall sustainability performance of the SC.

As far as the authors know, the literature still lacks a precise description of the main types of agents and their logic of operation, although this is extremely important and useful. In virtue of this, the aim of this paper is to investigate the behaviours of agents modelled in the agent-based simulations and their interactions within the modelled environment, to gain insights about if and how ABS can support the design of resilient and/or circular SC models. This closes an important gap in technical literature, by providing a clear guideline that can be used (either by academics and practitioners) to capture and reproduce the dependencies, and feedback loops, reflecting the complexities of real-world supply chain dynamics.

2. Methods

In a recent work (Moroni et al., 2024) we conducted a structured literature review in which 98 contributions were analysed to assess the impact of simulation in the design of innovative and environmentally sustainable supply chains. Of all contributions, 49% make use of DES, 37% make use of ABS, and the remaining 14% exploit a hybrid simulation approach (i.e., a combination of more than one simulation type).

In the present work, we deepened our previous research by focusing exclusively on the contributions dealing with agent-based models, being them exclusively ABS or a combination of ABS and other simulation typologies. As stated in the introduction, in fact, end-users play a pivotal role, and the full understanding of their behaviour is crucial for a proper design of the supply chain. It is therefore obvious that ABS, which allows practitioners to map and reproduce the end-users' behaviour and their mutual influences, is an indispensable and valuable operative tool.

Considering this, the 47 contributions dealing with ABS (our full dataset) were analysed through a full text reading. This led to the removal of 22 articles, that were deemed irrelevant for the goals of the analysis, either because the full text format was unavailable or because ABS was treated just theoretically, without providing a reproducible model and/or barely presenting any agent description if not at all.

The remaining 25 contributions were thoroughly analysed with the aim of gaining relevant information concerning the simulation models and the agent behaviours, as detailed in the next sections.

3. Agents' classification

We analysed and classified the 25 contributions in terms of the following four features:

- *Simulation adopted* - The simulation approach used in the analysed study; we recall that the approach can only be either a pure ABS or a hybrid model in which ABS is merged with DES and/or SD.
- *SC sector* - The sector of the modelled supply chain,

grouped into coherent market segments. Note that, if products' characteristics (e.g., specific distribution market, size or weight, production lead time, types of raw materials and consumables used) are not indicated, the sector is labelled as "Generic".

- *Agent types* – The agents used in the model, described in terms of their location and task within the SC.
- *Model description and main results* – A brief description that pinpoints the main features of the proposed model and its principal outcomes.

Due to space constraints, only 8 of the 25 contributions are detailed in Table 1, whether the other ones are just listed in Appendix A. These 8 contributions were selected as they make use of "dynamic and active" agents, characterised by a specific behaviour (that can even evolve over time due to exogenous events and/or to the reciprocal influence with other agents), decision-making processes, and communication capabilities. Also, they can initiate actions, take independent decisions and react to changes in the operating environment.

Conversely, agents of the other 17 papers are "static and passive". That is, they exhibit simple, non-interacting behaviour and/or their interactions are minimal or non-existent. Technically speaking if, as in the abovementioned cases, agents are homogeneous, their interaction are infrequent or simple (e.g. arrival and departure) and their behaviour remains constant over time, agents could be easily replaced by discrete-event simulation objects (i.e., ABS could be substituted by DES).

To better clarify this crucial point, a brief comparison of two papers (belonging to the two aforementioned categories) is reported next. We begin with a brief overview of the two contributions, followed by an explanation of the behaviour of the modelled agents.

1. Sahay et al. (2014) analyse the complexity of SC networks through a hybrid simulation (based on ABS and embedded optimization models) used to predict optimal operation in both synchronous and asynchronous decision-making strategies, within a SC. The modelled network is composed of four agent types: (i) *demand agent* who generates the demand; (ii) *warehouse agent* that regulates the replenishment of the inventory in a fixed lead time way; (iii) *production site agent* who stores products and regulates inventory by manufacturing products from raw materials; (iv) *supplier agent* that is responsible for transportation and inventory cost.

2. Ge et al. (2015) deal with the Canadian SC of wheat. Briefly, wheat is transferred from the farmer's truck to rail cars, where it is mixed with wheat of the same type collected from other farmers, and finally to merchant ships. The focus is on the quality control strategies used to avoid contamination between different types of wheat being transported. In the model, all possible contamination points are considered - from the moment a farmer delivers his/her harvest, until wheat is finally loaded onto merchant ships – and alternative testing strategies are reproduced using ABS. Two types of agents are considered: (i) *farmer agent*, who delivers the wheat and certifies/declares its type and origin and (ii) *handler agent*, who transports wheat to the ships being responsible for quality control. Farmer agents aim to balance their control efforts and technological investments to maximize their utility. Similarly, handlers must minimize costs (due to controls and contaminations penalties) to determine the optimal frequency of sampling and testing.

In the first paper the agents' behaviour is fixed and does not change over time. Also, the level of interaction among agents is low, as it only encompasses information exchanges triggering operating events (e.g., an order triggering production and delivery). These interactions have no effect at all on the decision-making models followed by the agents. Instead, in the second paper the behaviour of each agent is dynamically updated, based on the actions taken by the other agents. In fact, the technological level and the control efforts of each farmer is updated annually, depending on his/her experience and that of neighbouring farmers. More precisely: (i) control efforts increase with the number of tested or traced neighbouring farmers and decrease if neighbours are rarely or never traced, whereas (ii) the technological level grows with the number of neighbouring farmers detected to have caused contamination. Similarly, handlers readjust their testing frequency each year, based on the past performance of each farmer.

Table 1: Classification of main contributions

Reference	Simulation adopted	SC Sector	Agent types	Model description and main results
(Backs et al., 2021)	ABS	Textile	1. Manufacturer 2. Point of Sale 3. Consumer	The model can incorporate a broader spectrum of elements, encompassing normative social influence, direct experience, promotional activities, and interpersonal communication, among others. The simulation results suggest that these market characteristics significantly impacts outcomes and provides valuable support for decision-makers, enabling them to explore various scenarios and identify the most suitable individual strategy.
(Buurma et al., 2017)	ABS	Food & Beverage	1. Customer 2. Retailer 3. Farmer 4. NGO	This agent-based simulation was made to validate hypothetical relationships and explore alternative development scenarios of sociotechnical innovations in the modelled food supply chain under its different actors' behaviours or external events. It has been showed that public pressure and activist involvement are crucial for driving sociotechnical innovations in food production, leading to the adoption of more animal-friendly practices and products.
(Ge et al., 2015)	ABS	Agriculture	1. Farmer 2. Handler	This study models the wheat supply chain from the moment a farmer delivers their harvest to when the wheat is loaded onto merchant ships. It compares analytic models and agent-based simulation to identify effective wheat quality testing strategies. Results show that a grain handling system using well-designed testing strategies can effectively reduce the risks of misrepresentation or contamination, all while maintaining relatively low handling costs. Additionally, this simulation acts as a foundation for identifying a group of testing strategies that are most compatible with a specific regulatory target.
(Huang & Song, 2018)	ABS	Agriculture	1. Farmer 2. Grain Trading Enterprise (GTE) 3. Grain Processing Enterprise (GPE) 4. Seller	The proposed model captures the complex interactions and behaviours of bidders influenced by financial and production perspectives within the supply chain. A case study based on real data validates the approach, demonstrating its effectiveness in optimizing auction policies under various supply and demand scenarios (i.e., Oversupply, Balance, Insufficient supply), ultimately aiding in profit maximization and inventory cost control for large enterprises. The paper also explores the sensitivity of decision variables and provides the following managerial insights: the ratio between the minimum initial bid and the market price is relatively less impactful on the seller's profit compared to the auction lot size and auction time interval in a scenario of insufficient supply.
(Sha & Srinivasan, 2016)	ABS	Chemical	1. Market 2. Customer 3. Order coordinator 4. Warehouse 5. Replenishment Coordinator 6. Plant 7. Logistic	In this simulation each agent operates based on specific rules and policies, pursuing its own interests while interacting with other agents to drive the supply chain's performance. The dynamics of the supply chain emerge from these interactions. The agent-based simulation model effectively captures the complexities of the given supply chain, providing valuable insights into fleet sizing and management. The study shows that the optimal fleet size for supply chain performance is influenced by the decision-makers' policies, and enhancements in tank car repositioning policy can notably improve performance without the need to expand the fleet.
(Taghikhah et al., 2021)	ABS-DES-SD	Food & Beverage	1. Supplier 2. Manufacturer 3. Retailer 4. Consumer	This model merges agent-based, discrete-event, and system dynamics modelling, using a wine supply chain as a case study. The simulation model considers not just operational aspects such as price, quantity, and lead time, but also behavioural elements like attitude, perceived control, social norms, habits, and personal objectives of both food suppliers and consumers, with the aim of promoting organic farming. The proposed model outperforms traditional supply chain models by effectively integrating feedback between consumers and producers. This integration aids in the analysis of strategies that can encourage farmers to adopt organic agriculture. The results also suggest that without the involvement of intermediaries, the transition towards sustainable agriculture driven by consumer demand could be a lengthy process.

Reference	Simulation adopted	SC Sector	Agent types	Model description and main results
(Zhang, 2015)	ABS	Generic	1. Customer 2. Manufacturer 3. Supplier	An agent-based simulation model for the diffusion of collaborative technological innovations in supply chains. The results show that the diffusion of technological innovation in a collaborative supply chain differs from that of traditional technological innovation. Furthermore, the relationship between suppliers and manufacturers plays a significant role in influencing the pace and effectiveness of this diffusion.
(Zhao et al., 2019)	ABS	Generic	1. Manufacturer 2. Supplier	An agent-based model to show how the firms' adaptive behaviours can leverage competition relationships within a supply chain network. The simulation provides insights into how disruptions propagate and how firms adapt to maintain operations, illustrating the resilience and adaptability of firms in a dynamic economic environment.

4. Results and Discussion

Quite surprisingly, our classification shows a very limited use of ABS, at least in the supply chain context. As above mentioned, in fact, only 25 papers (of the initial set of 98 works) explicitly deal with ABS. Also, and perhaps more important, only 8 works make use of adaptive agents driven by specific utility functions, whose behaviour, in the simulation context, evolve due to the mutual interaction among the agents. Conversely, all the other works, while considering complex SC and interesting case studies, do not seem to exploit the full potentiality of ABS. Agents are in fact static and predetermined and could easily be replaced, without any loss, by the more common 'discrete event' simulation objects.

Our analysis also reveals that: (i) there is no difference in the level of complexity between SCs modelled with DES and ABS and (ii) there is no noticeable upward trend in publications using ABS. Due to these issues, our initial hypothesis, which stated that to model complex supply chains (i.e., linear or circular) an ABS or a hybrid simulation model is needed, cannot be regarded as validated. This does not imply that our original hypothesis is incorrect, but simply that it is not supported by the evidence emerging from this study.

Probably, the currently established use of DES models in the domain of operation management, and therefore the greater experience of the researchers in using this paradigm, seems to limit and hinder the adoption of ABS models in SC. Not only, ABS models are less known, but they also pose a greater implementation challenge as they require an accurate description of the agents' behaviours, without which the model loses effectiveness. This is a critical issue, that can discourage researchers and practitioners that are not familiar with ABS to adopt this alternative and powerful simulation approach.

To overcome this constraint and promote the introduction of ABS, we propose two possibilities: (i) to broaden the scope by considering models developed in areas where this simulation approach is preferred (e.g., social sciences, ecology, ecosystems), as some behavioural models can be reused in the logistics field; (ii) to request that any researcher publishing in this field describes their model in a more precise and reproducible way so as to become a sort of "guideline" for future studies.

5. Conclusions and future works

This work deepens the analysis of a previous research (Moroni et al., 2024), where we performed a structured literature review to identify a comprehensive set of contributions performing ABS or DES simulation approaches, either in a stand-alone or in a hybrid way, to design and/or to optimize sustainable SCs. The goal was to understand how ABS can support the transition of supply chains towards more sustainable and circular models.

In this work we considered 25 contributions of the former dataset that made use of ABS, with the aim of examining the behaviours of agents modelled in the agent-based simulations and their interactions within the simulated environment. Our main outputs are two tables: (i) Table 1, showed in section 3, and (ii) table in Appendix A, were we categorised the 25 contributions according to the simulation adopted, the SC sector, the types of agents modelled, presenting a brief description of the models and their main results. In addition, interesting considerations from the analysis made are presented in section 4, where we observed the underutilization of agent-based simulation in supply chain studies. The complexity level was similar in SCs modelled with discrete event simulation and ABS, and no trend was observed in ABS publications. We therefore suggested to broaden the scope to consider models from fields where ABS is preferred and encouraging researchers to describe their models in a more precise and reproducible manner.

Despite the quality of the results, some limitations must be reported: (i) firstly, we only considered ABS simulations of SC based on the criteria of our previous work. Therefore, the spectrum of supply chains covered by this analysis is not global, but rather partial; (ii) secondly, this research was limited to articles present in scientific archives until February 2024, therefore some new articles on the same topics may have emerged; (iii) we did not obtain significant insights regarding the use of ABS in sustaining SC transition towards more sustainable SC modes (e.g., circular supply chain).

Future works may conduct further investigations in understanding the possible existence of any correlation between characteristics of SC (in terms of product type, SC structure, and presence of returning flows) and the use of ABS as the primary simulation approach. Moreover, mapping agents' behaviours, ranging from production scheduling and inventory management to pricing strategies and purchasing decisions, and delving into how they are modelled (i.e., predefined if-then rules, utility functions, algorithms, heuristics, etc.), allows to study the mechanisms that govern their behaviours and influence their interactions. In fact, by incorporating insights into citizen behaviours and preferences, supply chain designers can develop strategies that align with societal values, minimize environmental impacts, and promote economic prosperity. Furthermore, from consumer preferences for eco-friendly products to stakeholders' engagement in circular economy initiatives, accounting for citizen behaviours enhances the resilience and effectiveness of sustainable supply chain designs.

In conclusion, by considering the behaviour of other SC stakeholders, sector-specific information can be obtained (e.g. a mutual influence between two actors estimated over a certain distance, leading to behavioural changes) in a way that would be relevant when incorporated into future models, as it would allow more realistic scenarios to be simulated.

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References

Backs, S., Jahnke, H., Lüpke, L., Stücken, M., & Stummer, C. (2021). Traditional versus fast fashion supply chains in the apparel industry: an agent-based simulation approach. Annals of Operations Research, 305(1–2), 487–512. https://doi.org/10.1007/s10479-020-03703-8

Barbosa, C., & Azevedo, A. (2019). Assessing the impact of performance determinants in complex MTO/ETO supply chains through an extended hybrid modelling approach. International Journal of Production Research, 57(11), 3577–3597. https://doi.org/10.1080/00207543.2018.1543970

Barbosa, C., Malarranha, C., Azevedo, A., Carvalho, A., & Barbosa-Póvoa, A. (2023). A hybrid simulation approach applied in sustainability performance assessment in make-to-order supply chains: The case of a commercial aircraft manufacturer. Journal of Simulation, 17(1), 32–57. https://doi.org/10.1080/17477778.2021.1931500

Behdani, B., Lukszo, Z., & Srinivasan, R. (2019). Agent-oriented simulation framework for handling disruptions in chemical supply chains. Computers and Chemical Engineering, 122, 306–325. https://doi.org/10.1016/j.compchemeng.2018.09.027

Buurma, J., Hennen, W., & Verwaart, T. (2017). How social unrest started innovations in a food supply chain. JASSS, 20(1). https://doi.org/10.18564/jasss.3350

Cannella, S., Mauro, C. Di, Dominguez, R., Ancarani, A., & Schupp, F. (2019). An exploratory study of risk aversion in supply chain dynamics via human experiment and agent-based simulation. International Journal of Production Research, 57(4), 985–999. https://doi.org/10.1080/00207543.2018.1497817

Choi, T. Y., Dooley, K. J., & Rungtusanatham, M. (2001). Supply networks and complex adaptive systems: control versus emergence. Journal of Operations Management, 19(3), 351–366. https://doi.org/10.1016/S0272-6963(00)00068-1

Elkamel, M., Rabelo, L., & Sarmiento, A. T. (2023). Agent-Based Simulation and Micro Supply Chain of the Food–Energy–Water Nexus for Collaborating Urban Farms and the Incorporation of a Community Microgrid Based on Renewable Energy. Energies, 16(6). https://doi.org/10.3390/en16062614

Gardiner, D., & Reefke, H. (2019). Operations Management for Business Excellence: Building Sustainable Supply Chains. Taylor & Francis.

Ge, H., Gray, R., & Nolan, J. (2015). Agricultural supply chain optimization and complexity: A comparison of analytic vs simulated solutions and policies. International Journal of Production Economics, 159, 208–220. https://doi.org/10.1016/j.ijpe.2014.09.023

Glew, R., Hernandez, M. P., & McFarlane, D. (2021). Analysing the effect of food supply chain traceability on product waste. Operational Research Society 10th Simulation Workshop, SW 2021 - Proceedings, 145–154. https://doi.org/10.36819/SW21.015

Guide, V. D. R., & Van Wassenhove, L. N. (2006). Closed-Loop Supply Chains: An Introduction to the Feature Issue (Part 1). Https://Doi.Org/10.1111/j.1937-5956.2006.Tb00249.x, 15(3), 345–350. https://doi.org/10.1111/J.1937-5956.2006.TB00249.X

Huang, J., & Song, J. (2018). Optimal inventory control with sequential online auction in agriculture supply chain: an agent-based simulation optimisation approach. International Journal of Production Research, 56(6), 2322–2338. https://doi.org/10.1080/00207543.2017.1373203

Kale, V. (2016). Enhancing enterprise intelligence: leveraging ERP, CRM, SCM, PLM, BPM, and BI. CRC Press. https://www.barnesandnoble.com/w/enhancing-enterprise-intelligence-vivek-kale/1128424824?ean=9781498788199

Lehner, R., & Elbert, R. (2023). Cross-actor pallet exchange platform for collaboration in circular supply chains. International Journal of Logistics Management, 34(3), 772–799. https://doi.org/10.1108/IJLM-03-2022-0139

Li, X., Kizito, R., & Paula, T. I. (2018). An agent-based simulation framework for supply chain disruptions and facility fortification. Proceedings - Winter Simulation Conference, 2018-Decem, 821–832. https://doi.org/10.1109/WSC.2018.8632475

Ma, K., Wang, L., & Chen, Y. (2018). A collaborative cloud service platform for realizing sustainable make-to-order apparel supply chain. Sustainability (Switzerland), 10(1). https://doi.org/10.3390/su10010011

Matopoulos, A., Barros, A. C., & van der Vorst, J. G. A. J. (2015). Resource-efficient supply chains: A research framework, literature review and research agenda. Supply Chain Management, 20(2), 218–236. https://doi.org/10.1108/SCM-03-2014-0090/FULL/PDF

Medini, K., & Rabénasolo, B. (2014). Analysis of the performance of supply chains configurations using multi-agent systems. International Journal of Logistics Research and Applications, 17(6), 441–458. https://doi.org/10.1080/13675567.2014.894183

Moroni, F., Viola, A., Gallo, M., Romagnoli, G., & Zammori, F. (2024). Do we really need simulation for a transition towards Circular Supply Chain Management? A possible answer from scientific literature. APMS (in Press).

Mortazavi, A., Khamseh, A. A., & Azimi, P. (2015). Designing of an intelligent self-adaptive model for supply chain ordering management system. Engineering Applications of Artificial Intelligence, 37, 207–220. https://doi.org/10.1016/j.engappai.2014.09.004

Naghavi, S., Karbasi, A., & Kakhki, M. D. (2020). Agent based modelling of milk and its productions supply chain and bullwhip effect phenomena (Case Study: Kerman). International Journal of Supply and Operations Management, 7(3), 279–294. https://doi.org/10.22034/IJSOM.2020.3.6

Nguyen, T. T. B. (2021). Which Node of Supply Chain Suffers Mostly to Disruption in the Pandemic? Journal of Distribution Science, 19(11), 59–68. https://doi.org/10.15722/jds.19.11.202111.59

Onggo, B. S., & Utomo, D. S. (2021). Dairy supply chain in west Java: Modelling using agent-based simulation and reporting using the stress guidelines. Operational Research Society 10th Simulation Workshop, SW 2021 - Proceedings, 295–304. https://doi.org/10.36819/SW21.032

Sahay, N., Ierapetritou, M., & Wassick, J. (2014). Synchronous and asynchronous decision making strategies in supply chains. Computers and Chemical Engineering, 71, 116–129. https://doi.org/10.1016/j.compchemeng.2014.07.005

Sha, M., & Srinivasan, R. (2016). Fleet sizing in chemical supply chains using agent-based simulation. Computers and Chemical Engineering, 84, 180–198. https://doi.org/10.1016/j.compchemeng.2015.08.015

Taghikhah, F., Voinov, A., Shukla, N., Filatova, T., & Anufriev, M. (2021). Integrated modeling of extended agro-food supply chains: A systems approach. European Journal of Operational Research, 288(3), 852–868. https://doi.org/10.1016/j.ejor.2020.06.036

Tan, J., Jiang, G., & Wang, Z. (2019). Evolutionary game model of information sharing behavior in supply chain network with agent-based simulation. International Journal of Intelligent Information Technologies, 15(2), 54–68. https://doi.org/10.4018/IJIIT.2019040104

Weetman, C. (2020). A circular economy handbook : how to build a more resilient, competitive and sustainable business (2nd ed.). Kogan Page.

Zhang, H. P. (2015). An agent-based simulation model for supply chain collaborative technological innovation diffusion. International Journal of Simulation Modelling, 14(2), 313–324. https://doi.org/10.2507/IJSIMM14(2)CO6

Zhao, K., Zuo, Z., & Blackhurst, J. V. (2019). Modelling supply chain adaptation for disruptions: An empirically grounded complex adaptive systems approach. Journal of Operations Management, 65(2), 190–212. https://doi.org/10.1002/joom.1009

Zhu, A., Han, Y., & Liu, H. (2024). Effects of adaptive cooperation among heterogeneous manufacturers on supply chain viability under fluctuating demand in post-COVID-19 era: an agent-based simulation. International Journal of Production Research, 62(4), 1162–1188. https://doi.org/10.1080/00207543.2023.2178370

Appendix A. Classification Table of the remaining articles

Reference	Simulation adopted	SC Sector	Agent types	Model description and main results
(Barbosa & Azevedo, 2019)	ABS-DES-SD	Generic	1. Customer 2. Manufacturer 3. Supplier	A hybrid simulation model combining system dynamics, discrete event simulation, and agent-based simulation to assess the impact of various determinants such as workload, complexity, outsourcing, design reuse, project type, and knowledge/experience with technology on supply chain performance. The authors showed evidence of association between all performance determinants and the project time and cost, while no evidence of association between the design reuse, project type determinants, manufacturing and assembly time has been observed.
(Barbosa et al., 2023)	ABS-DES-SD	Aeronautic	1. Customer 2. Manufacturer 3. Supplier 4. Material Transfer Point 5. Transport Agent	A hybrid simulation model for assessing sustainability performance in make-to-order supply chains, specifically in the aerospace industry. The authors demonstrated the model potential as a decision support tool in a real case scenario.
(Behdani et al., 2019)	ABS	Chemical	1. Customer 2. Manufacturer 3. Supplier	An agent-based simulation framework designed to manage disruptions in chemical supply chains. The authors showed the framework's ability in helping decision-makers to evaluate the impact of disruptions, experiment with various management strategies, and ultimately improve the resilience and performance of supply chains.
(Cannella et al., 2019)	ABS	Generic	1. Retailer 2. Wholesaler 3. Distributor 4. Manufacturer	A combination of agent-based simulation and human experiments that explores the influence of individual risk aversion on supply chain dynamics. As result, it is noticed that while supply chains with more risk-averse partners perform worse operationally, the ones with highly risk-averse retailers maintain high customer service levels, regardless of the risk aversion of other echelons.
(Elkamel et al., 2023)	ABS	Agriculture	1. Farmer 2. Household 3. Microgrid 4. Electricity grid 5. Water	An agent-based modelling framework to efficiently manage food, energy and water resources in urban farm settings, decreasing food waste, and increasing the food availability for the surrounding community. The framework shows that a regular communication between farms reduces significantly food waste and increase fresh food availability for local community. Moreover, the simulation results noticed that the community microgrids aided in the generation of energy from renewable sources (solar and wind), highlighting the potential for CO_2 emissions reduction.
(Glew et al., 2021)	ABS	Food & Beverage	1. Retailer 2. Transporter 3. Distributor 4. Grower	An agent-based simulation model to study the impact of traceability on food waste reduction in the fresh food supply chain. The simulation showed that traceability systems can significantly reduce food waste due to perishability, with the greatest reduction observed by retailers and final stage logistics providers.
(Lehner & Elbert, 2023)	ABS	Generic	1. Shipper 2. Forwarder 3. Consignee 4. Pallet shop	A development of a digital cross-actor pallet exchange platform aimed at improving efficiency in circular supply chains, through an agent-based simulation model with mathematical optimization. The platform can shorten transport routes, balance debts and receivables, and reduce the overall quantity of pallets in the system.
(Li et al., 2018)	ABS	Generic	1. Customer 2. Distributor	An agent-based simulation framework to study supply chain disruptions and facility fortification. The results show that fortifying the most important facilities can significantly reduce the total network cost during disruptions, providing insights into optimal fortification strategies to mitigate worst-case losses in supply chain networks.

Reference	Simulation adopted	SC Sector	Agent types	Model description and main results
(Ma et al., 2018)	ABS	Textile	1. Customer 2. Supplier 3. Collaborative Cloud Service Platform	A Collaborative Cloud Service Platform (CCSP) designed to optimize the sustainable make-to-order apparel supply chain. CCSP model offers comprehensive benefits, particularly for small and medium-sized enterprises (SMEs) in the apparel industry, by enhancing supply chain collaboration and resource sharing.
(Medini & Rabénasolo, 2014)	ABS	Generic	1. Supply Chain 2. Source 3. Make 4. Deliver 5. Client 6. Supplier	A dynamic supply chain configuration that adapts to market changes and uses agent-based simulation to assess performance. The simulation demonstrated that supply chain connectivity and competition significantly impact performance indicators like order fulfilment and turnover.
(Mortazavi et al., 2015)	ABS	Generic	1. Retailer 2. Distributor 3. Manufacturer 4. Supplier	An intelligent self-adaptive model for supply chain ordering management, integrating agent-based simulation with a reinforcement learning algorithm to face non-stationary customer demands. This simulation-based optimization framework can effectively manage inventory and ordering policies, minimizing costs while maintaining high service levels.
(Naghavi et al., 2020)	ABS	Food & Beverage	1. Farmer 2. Industry 3. Distributor	An agent-based modelling study of the milk supply chain to analyse the implications of the bullwhip effect issues. ABS showed to be effective in reducing the bullwhip effect in the authors' scenarios, even eliminating it in some cases.
(Nguyen, 2021)	ABS	Generic	1. Retailer 2. Wholesaler 3. Manufacturer	An Agent-based simulation to evaluate the cost-efficiency and customer waiting time, associated with different inventory levels of each supply chain member, when using inventory buffers. The study's outcomes offer insights for decision-makers to adjust inventory levels and for policymakers to sustain manufacturing activities under pandemic restrictions, addressing excessive demand and potential supply disruption risks.
(Onggo & Utomo, 2021)	ABS	Food & Beverage	1. Farmer 2. Cooperative 3. Patch	An agent-based simulation study of a dairy supply chain, focusing on the behaviour of smallholder farmers and their impact on milk production and cow population. The results show that ABS model can estimate the qualitative impact of policy interventions on the dairy supply chain studied.
(Sahay et al., 2014)	ABS	Generic	1. Demand Agent 2. Warehouse 3. Production site 4. Supplier	The model aim is to predict optimal operation in both synchronous and asynchronous decision-making strategies in supply chain. It is observed that synchronous interactions result in the lower cost compared to asynchronous interactions. However, optimized asynchronous interactions can perform better than synchronous interactions without optimization.
(Tan et al., 2019)	ABS	Generic	1. Supplier 2. Manufacturer	The model analyses how different penalties and information sharing risk costs affect the evolution of information sharing behaviour among the enterprises involved. The simulation explores the evolution of information sharing behaviours between these agents using evolutionary game theory. The main results indicate that greater penalties and risk control effectively promote cooperation and information sharing within supply chain networks.
(Zhu et al., 2024)	ABS	Textile	1. Large manufacturer 2. Small-Medium size manufacturer	An agent-based model to simulate the viable situation of heterogeneous supply systems by considering three behavioural rules (i.e., cooperation establishment, win-win cooperation, and cooperation priority). The simulation showed that close cooperation between large and small-medium sized manufacturers improves supply chain viability, especially under fluctuating demand.