Interactive Visualisation for Supply Chain Simulation Models

Prakasa Kandasamy Pandian Sivanesa Pandian

Masters Applied IT

Fontys University of Applied Sciences

Eindhoven

Abstract

Supply chain simulation models support planning and decision-making, but their value depends on how effectively users can interpret model outputs. This is particularly relevant for small and medium-sized enterprises (SMEs), where analytical expertise is often limited. Interactive visualisation has been proposed as a way to improve the accessibility of complex simulation models, yet empirical evidence on its impact on user understanding remains limited.

This study examines how interactive visualisation influences user's understanding of supply chain simulation models compared to a static model. Using a research-through-design approach, an interactive visualisation prototype was developed and evaluated against an existing static model. A mixed-methods evaluation was conducted with nine participants, including SME professionals, supply chain experts, and students. All participants interacted with both the models each 5 min and right after completed a System Usability Scale (SUS) questionnaire and a comparative evaluation, while qualitative feedback was collected only from SME professionals through think a loud session.

The results show that the interactive visualisation was perceived as more usable and easier to understand than the static model, particularly in terms of clarity, bottleneck identification, and interpretation of timing information. Although the study is exploratory and based on a small sample, the findings suggest that interactive, user-centred visualisation can improve the interpretability of supply chain simulation models for SMEs.

Keywords: Supply chain simulation, Interactive visualisation, SME decision support, Usability, User understanding

Introduction

Supply chains are complex, interconnected systems that require careful planning and informed decision-making. Simulation models are widely used to analyse production flow, identify bottlenecks, estimate lead times, and explore "what-if" scenarios in order to support operational and strategic decisions [Error! Reference source not found.][1]. Although such models are often technically robust, t heir practical value depends strongly on how well users are able to understand and interpret the information they present [2].

In practice, many supply chain simulation models rely on static, diagram-based, or highly technical representations. While these representations may be accurate, they are often difficult for non-expert users to interpret, particularly in small and medium-sized enterprises (SMEs) where specialised analytical expertise is limited [4][5]. As a result, insights generated by simulation models may be misunderstood, underused, or ignored in decision-making processes, reducing their effectiveness as decision-support tools.

Interactive visualisation has been identified as a promising approach to improve the accessibility and interpretability of complex systems. Previous research indicates that interactive tools enable exploration, make dependencies and delays more visible, and support users in adapting to changing conditions [Error! Reference source not found.][6]. Human-centred visualisation approaches e mphasise clarity, transparency, and accessibility, aiming to support users with varying levels of expertise rather than assuming advanced technical knowledge [7].

From a cognitive perspective, poorly structured visualisations can overload users and reduce comprehension. Research on cognitive load and data visualisation shows that clear visual hierarchy, grouping of related information, and guided interaction can significantly improve understanding while reducing mental effort [Error! Reference source not found.][8]. These principles are particularly r elevant for supply chain simulations, which often involve large amounts of interconnected and time-dependent information.

Despite these insights, relatively little research has focused specifically on how SME users understand and interpret supply chain simulation models in practice. Existing studies often prioritise technical optimisation or focus on large industrial contexts, rather than examining how non-expert users make sense of simulation behaviour [9][10]. Furthermore, few studies directly compare traditional static simulation representations with interactive visualisations to evaluate their effects on user understanding, perceived clarity, and confidence.

This study addresses this gap by examining how interactive visualisation can support user understanding of supply chain simulation models within an SME context. An existing static supply chain simulation model is used as a baseline and compared with a newly designed interactive visualisation prototype. The prototype is treated as a research instrument rather than a finished product, enabling systematic investigation of how visual and interaction design choices influence interpretation and sense-making.

Following a research-through-design approach [15], the study combines a SUS-style usability questionnaire, a comparative evaluation between static and interactive representations, and short qualitative interviews. Through this mixed-methods evaluation, the research explores whether and how interactive visualisation influences user's ability to understand process flow, timing, buffer behaviour, and bottlenecks in supply chain simulation models, in comparison to a static representation.

Methods

Research Approach

This study followed a research-through-design approach to investigate how interactive visualisation influences SMEs' understanding of supply chain simulation models. Research-through-design is appropriate when the research focus lies on user understanding, interaction, and interpretation of complex systems, and when knowledge is generated through the design, implementation, and evaluation of a research artefact **[15]**.

In this study, an interactive supply chain visualisation prototype was developed as a research instrument. The prototype enabled a systematic comparison between an existing static simulation model and a redesigned interactive version. The aim was not to optimise a final product, but to use the prototype to examine how visual and interaction elements affect user comprehension, perceived clarity, and usability.

Design Framework: Design Thinking as a Structuring Tool

Design Thinking was applied as a process framework to structure the research activities across five phases: empathise, define, ideate, prototype, and test **[17]**. It was not used as a data collection method, but as a means to organise the development of the research artefact.

The empathise phase focused on understanding SME users through background research and an exploratory user survey. The define phase involved formulating the research problem and design goals based on user needs and limitations of the existing model. During ideation, visual and interaction concepts were explored through sketches and low-fidelity designs. These concepts were translated into Figma designs and a functional React prototype during the prototyping phase. Finally, the test phase evaluated user understanding and usability through structured user testing.

Within each phase, appropriate scientific research methods were applied to generate evidence and validate design decisions.

Participants

Nine participants took part in the evaluation. Participants were selected using purposive sampling to include users with varying levels of familiarity with supply chain concepts. The participant group consisted of three SME professionals, four students working on supply chain-related projects, and two supply chain domain experts.

All participants completed the quantitative evaluation through an online questionnaire. In addition, the three SME professionals participated in synchronous evaluation sessions that included continuous think-aloud interaction and short follow-up interview questions. The remaining participants (students and experts) did not take part in interviews and contributed only through the online questionnaire.

Participants were recruited through the researcher's professional and academic network. Inclusion criteria required participants to have either professional experience in the supply chain domain or academic experience through coursework or projects related to supply chain management. Participant's prior experience with supply chain simulations was mixed.

Experimental Setup

The evaluation was conducted online. Participants interacted with the models using their own laptops/desktops. The interactive visualisation was implemented as a web-based application using the React framework and accessed through a web browser. The static simulation model was presented as a non-interactive visual representation.

The evaluation compared two representations of the same supply chain simulation: an existing static model and a redesigned interactive visualisation prototype. The interactive prototype provided two complementary views: a dashboard view presenting aggregated performance indicators and timelines, and a model view visualising process flows, dependencies, and delay risks. Figures 1 and 2 illustrate the static and interactive models as they were presented to participants during the evaluation.

Figure 1. *Static supply chain simulation model used as the baseline representation in the evaluation.*

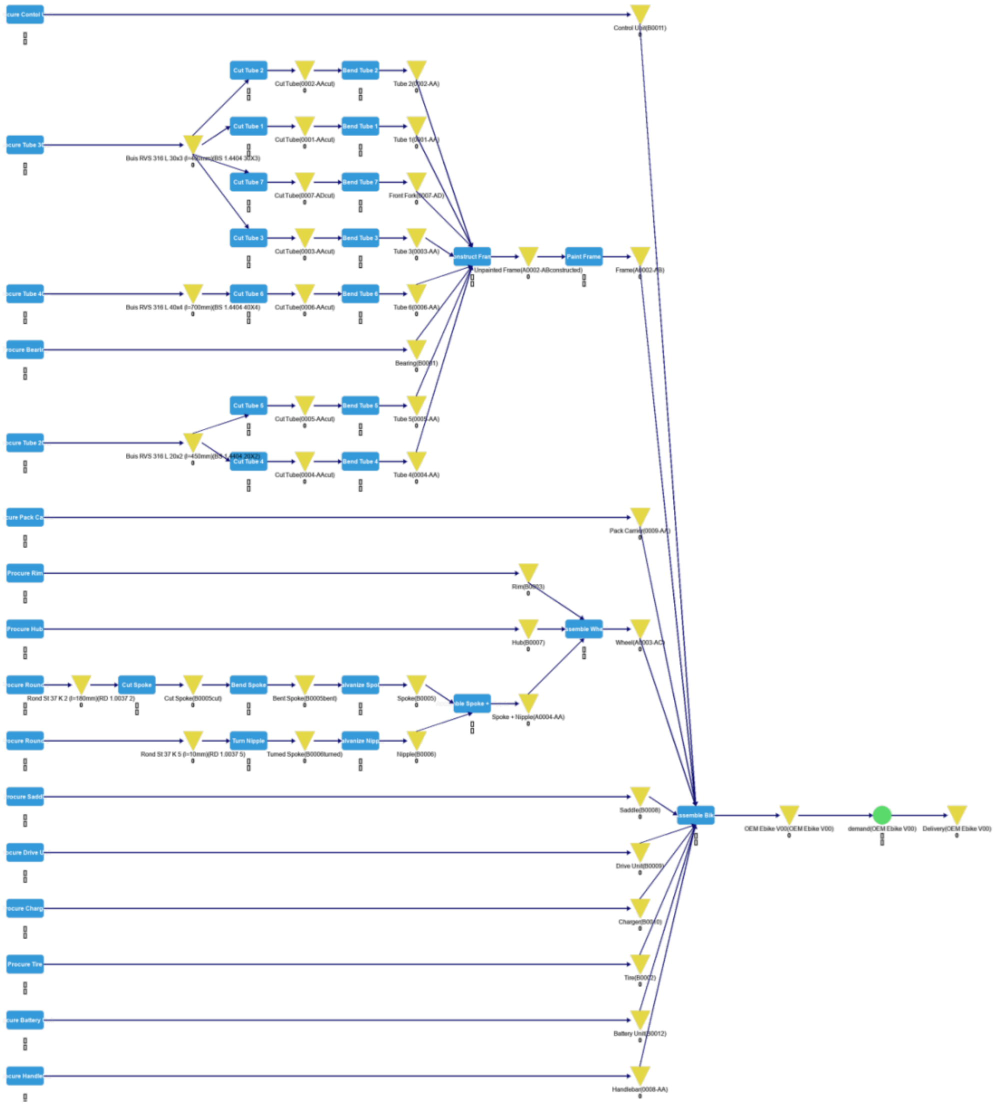
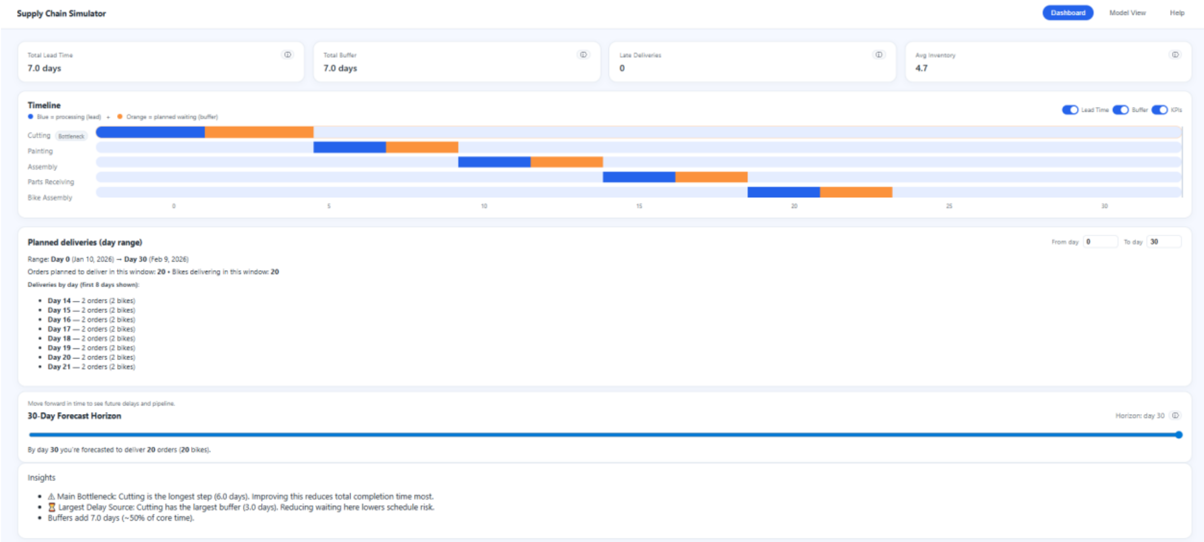
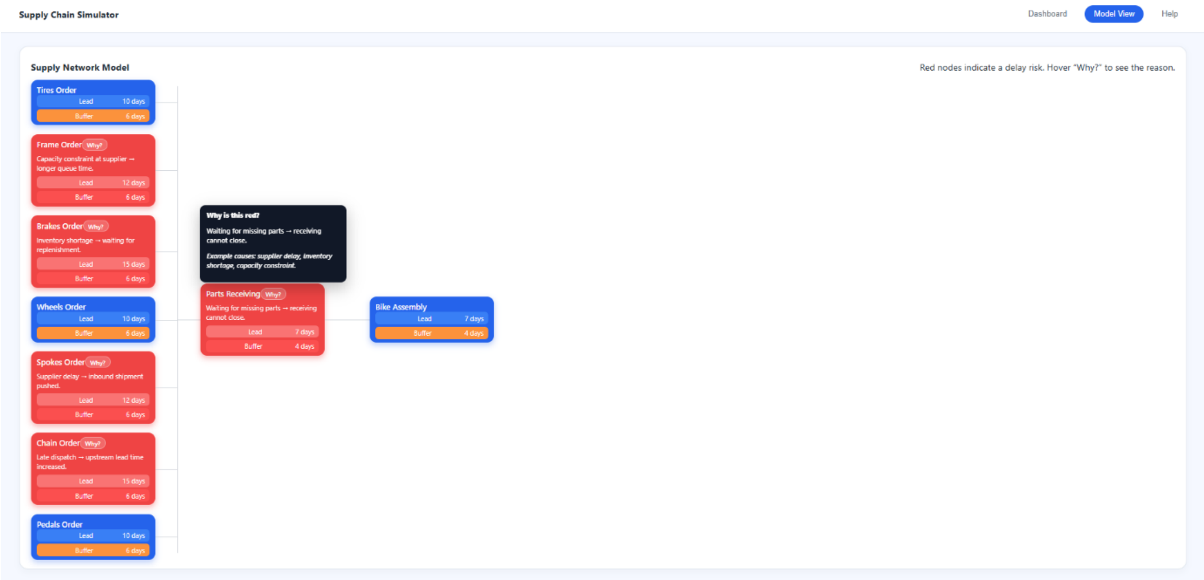


Figure 2. Interactive supply chain visualisation prototype used in the evaluation



(a) *dashboard view showing key performance indicators and timelines*



(b) *model view visualising process flows, dependencies, and delay risks*

Procedure

Two evaluation procedures were used. For the three SME professionals, synchronous online sessions were conducted. Each session began with a brief explanation of the study purpose and tasks. Participants were informed that some numerical values in the prototype were placeholders and were asked to focus on the visualisation rather than numerical accuracy. Participants first interacted with the static simulation model for approximately five minutes, followed by interaction with the interactive visualisation prototype for approximately five minutes. During interaction, participants were asked to think aloud continuously. After completing both interactions, participants answered a short set of follow-up interview questions.

For the remaining six participants (students and experts), the evaluation was conducted asynchronously using a Google Form. Participants received written instructions explaining the purpose of the study, the order of interaction, and the tasks to perform. They were instructed to first review the static model, then explore the interactive prototype, and finally complete the questionnaire. No interviews or think-aloud sessions were conducted for these participants.

Data Collection

Three types of data were collected:

Usability Questionnaire:
All participants completed the standard System Usability Scale (SUS), consisting of ten standard questions rated on a five-point Likert scale **[18]**. The questionnaire was administered via Google Forms after participants interacted with the interactive visualisation.

Comparative Evaluation:
All participants completed three Likert-scale questions comparing the static and interactive models on ease of understanding, clarity of timing information, and ability to identify bottlenecks. These questions were included in a different Google Form and answered after participants had interacted with both models.

Qualitative Feedback:
Qualitative data were collected only from the three SME professionals through continuous think-aloud interaction and short follow-up interview questions during the synchronous evaluation sessions.

Data Analysis

Due to the small sample size (n = 9) and the ordinal nature of the questionnaire data, quantitative results were primarily analysed descriptively using medians and interquartile ranges (IQR). To exploratorily examine whether differences between ratings of the static and interactive models were consistent across participants, Wilcoxon Signed-Rank Tests were conducted for the comparative evaluation measures. This non-parametric test is appropriate for paired ordinal data and small samples.

Qualitative data from the SME think-aloud sessions and interviews were analysed using thematic summarisation. Repeated themes were identified and used to contextualise and support the quantitative findings.

Results

This section presents the results of the evaluation of the interactive supply chain visualisation. The findings are based on a combination of a SUS-style usability questionnaire, a comparative evaluation between the static and interactive models, and short qualitative insights from user interviews. Due to the exploratory nature of the study and the small sample size (n = 9), results are analysed descriptively.

Participant Overview

Nine participants took part in the user evaluation. The participant group included SME professionals, a supply chain domain expert, and students acting as proxy users. All participants interacted with both the static (old) supply chain simulation model and the interactive (new) visualisation, allowing for direct comparison within the same session.

Usability Results: SUS-Style Questionnaire

After interacting with the interactive visualisation, participants completed a SUS-style questionnaire consisting of ten items rated on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree). The questionnaire assessed perceived usability, complexity, confidence, and learnability.

Table 1 presents the descriptive results using medians and interquartile ranges (IQR), which are appropriate for ordinal data and small samples.

Table 1

Descriptive SUS-style questionnaire results (n = 9)

Item	Statement (shortened)	Median	IQR
SUS1	Would like to use frequently	4	1
SUS2	Unnecessarily complex (R)	2	1
SUS3	Easy to use	4	1
SUS4	Need technical support (R)	2	1
SUS5	Elements well integrated	4	1
SUS6	Too much inconsistency (R)	2	1
SUS7	Learn quickly	4	1
SUS8	Very cumbersome (R)	1	1
SUS9	Felt confident	4	1
SUS10	Need to learn many things (R)	2	1

(R) = negatively phrased item

In addition to item-level descriptive analysis, a standard SUS score was calculated to provide a general usability indication. The interactive visualisation achieved a mean SUS score of 74.17, which is commonly interpreted as above-average usability. This score is reported for reference only and should be interpreted cautiously due to the small sample size and the exploratory nature of the study.

Overall, the results indicate that participants perceived the interactive visualisation as easy to use, well integrated, and confidence supporting. Negatively phrased items related to complexity, inconsistency, and effort received low median scores, suggesting that users did not find the system difficult or cumbersome.

Comparative Evaluation: Static Model vs Interactive Model

Participants evaluated both the old static model and the new interactive model on three aspects: ease of understanding, bottleneck identification, and clarity of lead and buffer times. Ratings were provided on five-point Likert scales (1 = very poor, 5 = very good).

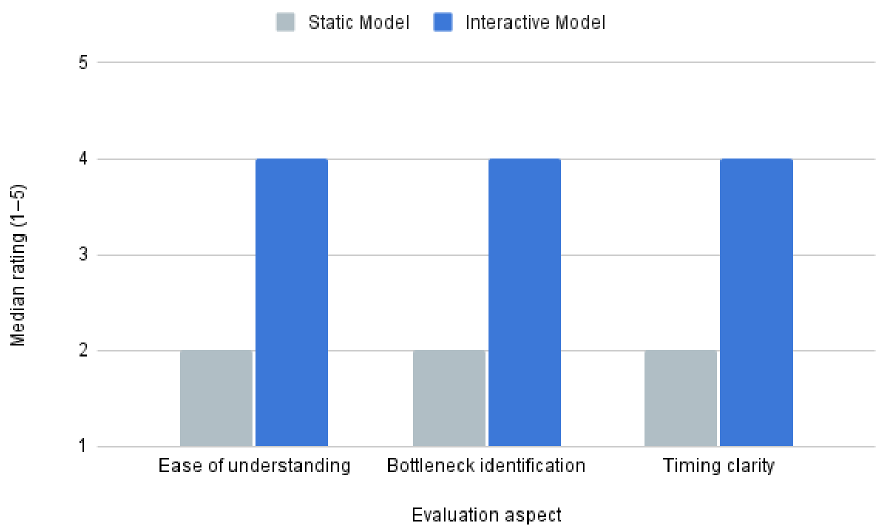
Table 2 summarises the descriptive comparison using medians and IQRs and Figure 3 provides a visual comparison of the median ratings for the static and interactive models across the three evaluated aspects.

***Table 2**. Descriptive comparison between Static and Interactive models (n = 9)*

Aspect	Static Model Median (IQR)	Interactive Model Median (IQR)
Ease of understanding	2 (1)	4 (1)
Bottleneck identification	2 (1)	4 (1)
Timing clarity (lead/buffer)	2 (1)	4 (1)

IQR (Interquartile Range) indicates the consistency of participant responses. Smaller IQR values reflect greater agreement, while larger values indicate more variability.

***Figure 3**. Median ratings for the static and interactive models across three evaluation aspects (n = 9).*



As shown in Table 2 and Figure 1, the interactive model received higher median ratings than the static model for all evaluated aspects. The small interquartile ranges indicate relatively consistent responses among participants. These results suggest that participants generally perceived the interactive visualisation as clearer and more supportive for understanding supply chain behaviour than the static representation.

Inferential Analysis: Wilcoxon Signed-Rank Test

To further explore whether the observed differences between the static and interactive models were consistent across participants, Wilcoxon Signed-Rank Tests were conducted for each comparative aspect. This non-parametric test is appropriate for paired ordinal data and small sample sizes.

Table 3. *Wilcoxon Signed-Rank Test results comparing static and interactive models (n = 9)*

Aspect	W	p-value
Ease of understanding	0	.010
Bottleneck identification	0	.011
Timing clarity (lead/buffer)	0	.004

W represents the Wilcoxon Signed-Rank test statistic, and p-values indicate whether the difference between the static and interactive models is statistically significant.

The Wilcoxon tests indicate statistically significant differences in favour of the interactive model for all three evaluated aspects. In all cases, participants rated the interactive model higher than the static model. Given the exploratory nature of the study and the limited sample size, these results are interpreted as supportive of the descriptive findings rather than as strong inferential evidence.

Qualitative Interview Insights

Short semi-structured interviews and think-aloud sessions were conducted during usability testing to provide contextual insight into the quantitative findings. Overall, participants indicated that the interactive visualisation supported faster and clearer understanding than the static model.

Participants highlighted dashboard-level KPIs as particularly helpful for gaining an initial overview, while colour coding and timeline visualisations made it easier to distinguish between processing time, buffer time, and delays. Several participants noted that bottlenecks were easier to identify visually in the interactive model than in the static representation.

At the same time, participants mentioned limitations related to placeholder data and minor inconsistencies between timelines and forecast information. These issues did not prevent understanding of the overall process but indicate areas for improvement in future iterations.

Discussion

This study examined how interactive visualisation influences user's understanding of supply chain simulation models compared to a traditional static representation. The results indicate that the interactive visualisation was perceived as easier to understand, clearer in communicating timing information, and more supportive for identifying bottlenecks than the static model. These findings are supported by both the SUS-style usability results and the comparative evaluation, which showed consistently higher ratings for the interactive model across all evaluated aspects. In addition, exploratory Wilcoxon Signed-Rank Tests indicated statistically significant differences in favour of the interactive model across all evaluated aspects, although these findings should be interpreted cautiously due to the small sample size.

A key finding of the study is that structuring information into different levels of detail supported user understanding. Participants benefited from having an overview through dashboard-level key performance indicators before exploring individual process steps. This layered presentation aligns with research on cognitive load and visualisation design, which suggests that reducing visual complexity and guiding user attention can improve comprehension of complex systems **[**Error! R eference source not found.**][8]**. In supply chain contexts, where models often contain interconnected and time-dependent information, such structuring can help users form a clearer mental model of system behaviour **[4][5]**.

The use of colour coding and timeline visualisations also played an important role in supporting interpretation. Results from the comparative evaluation showed higher ratings for timing clarity in the interactive model, and interview feedback indicated that users could more easily distinguish between processing time and buffer time. Prior research in human–computer interaction and data visualisation highlights that clear visual encoding of key variables, such as time and status, can reduce cognitive effort and improve decision-making quality **[**Error! Reference source not found.**][6]**. These findings s uggest that timeline-based visualisations are particularly effective for communicating temporal dynamics in supply chain simulations.

Interactive features such as zooming, time sliders, and contextual explanations further supported exploratory sense-making. Rather than passively observing a static diagram, users were able to interact with the model and explore how delays and bottlenecks affected downstream processes. This supports earlier studies showing that interactive "what-if" and exploratory tools enhance understanding by allowing users to actively engage with complex systems rather than relying solely on static representations **[**Error! Reference source not found.**][2][9]**. Such interaction is especially v aluable for non-expert users, who may lack the technical background required to interpret traditional simulation outputs.

Several limitations of this study should be considered when interpreting the results. First, the sample size was small (n = 9), and the participant group included proxy users such as students alongside SME professionals. While small samples are common and acceptable in usability and exploratory design research **[13][14]**, the findings cannot be generalised to all SME contexts. Second, the evaluation was conducted using a prototype with placeholder data and some known inconsistencies between timelines and forecast information. Although participants were still able to understand the overall process, these limitations may have affected perceived realism and trust in the model.

Despite these limitations, this study contributes to existing research by focusing specifically on user understanding rather than technical optimisation of supply chain simulation models. While previous work has demonstrated the potential of interactive visualisation for decision support **[**Error! Reference s ource not found.**][10]**, fewer studies have examined how non-expert SME users interpret simulation behaviour in practice. By treating the prototype as a research instrument, this study provides practical insights into how visual and interaction design choices influence clarity, confidence, and sense-making.

In conclusion, the findings suggest that interactive, user-centred visualisation has potential to improve the usability and interpretability of supply chain simulation models for SMEs. Design elements such as dashboards, timelines, colour coding, and interaction appear to play a crucial role in supporting user understanding. Although the results are exploratory, they indicate promising directions for future research and tool development. Further studies with larger and more representative samples, as well as fully implemented systems, are needed to validate and extend these findings.

References

1. Tripathi, P. (2021). *Building resilient supply chains using interactive visualization* (Master's thesis). Massachusetts Institute of Technology. https://hdl.handle.net/1721.1/139357
2. Min, J. U. (2004). *Supply chain visualization through web services integration* (Doctoral dissertation). ProQuest Dissertations & Theses Global. (ProQuest No. 3139127)
3. Kapoor, S. (2025). Human-centered visualization interfaces for sustainable supply chains. *Journal of Business & Management Studies*. DOI: Not available.
4. Blackhurst, J., Scheibe, K., & Johnson, D. (2018). Supply chain vulnerability assessment: A network-based visualization and clustering analysis approach. *International Journal of Production Economics*. 10.1016/j.pursup.2017.10.004
5. Hosseini, S., Ivanov, D., & Dolgui, A. (2024). Steel supply chain complexity and resilience assessment. DOI: Not available.
6. Padilla, L. M., Creem-Regehr, S. H., Hegarty, M., & Stefanucci, J. K. (2018). Decision making with visualizations: A cognitive framework across disciplines. *Cognitive Research: Principles and Implications, 3*(29). 10.1186/s41235-018-0120-9
7. Eberhard, U. (2021). The effects of visualization on judgment and decision-making. 10.1007/s11301-021-00235-8
8. Cabouat, A.-F**.** (2024). *Cognitive load and data visualization*. HAL-Inria. 10.17605/OSF.IO/PVRQH
9. Cheng, X. (2025). *Interactive data visualization for decision-making in digital government* (Doctoral dissertation). Delft University of Technology. 10.59490/dgo.2025.946
10. Khatri, S. (2022). Impact of data visualization on management decisions. *Journalspress*. DOI: Not available.
11. Pranggono, B., & Rahman, M. (2022). *Assessing digital readiness of small and medium enterprises*. Sheffield Hallam University Research Archive. 10.14569/IJACSA.2022.0130412
12. Kamariotou, M., & Kitsios, F. (2022). Digital strategy decision support systems: Agrifood supply chain management in SMEs. *Sensors, 22*(4), Article 1435. 10.3390/s22010274
13. Hirschey, J., Bickmore, T., & Johnston, J. (2018). Evaluating the usability and usefulness of a mobile app for atrial fibrillation. *JMIR Human Factors, 5*(2), e20. 10.2196/humanfactors.8004
14. Almasi, M., & Almasi, S. (2023). Usability evaluation of dashboards: A systematic literature review of tools. *BioMed Research International, 2023*, Article 6691243. 10.1155/2023/9990933
15. Zimmerman, J., Forlizzi, J., & Evenson, S. (2007). Research through design as a method for interaction design research. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 493–502). Association for Computing Machinery. 10.1145/1240624.1240704
16. Park, H., & McKilligan, S. (2018). A systematic literature review for human–computer interaction and design thinking process integration. In A. Marcus & W. Wang (Eds.), *Design, user experience, and usability: Theory and practice* (Lecture Notes in Computer Science, Vol. 10918). Springer. 10.1007/978-3-319-91797-9_50
17. Webster, J., & Watson, R. T. (2002). Analyzing the past to prepare for the future: Writing a literature review. *MIS Quarterly, 26*(2), xiii–xxiii. 10.2307/413231
18. Brooke, J. (1996). SUS: A "quick and dirty" usability scale. In P. W. Jordan, B. Thomas, B. A. Weerdmeester, & I. L. McClelland (Eds.), *Usability evaluation in industry* (pp. 189–194). Taylor & Francis. 10.1201/9781498710411-35