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From novice to expert: advancing step-by-step simulation guideline for urban logistics with an open-source simulation tool

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Abstract

Purpose – This research analyses challenges faced by users at various levels in planning and designing participatory simulation models of cities. It aims to identify issues that hinder experts from maximising the effectiveness of the SUMO tool. Additionally, evaluating current methods highlights their strengths and weaknesses, facilitating the use of participatory simulation advantages to address these issues. Finally, the presented case studies illustrate the diversity of user groups and emphasise the need for further development of blueprints.

Design/methodology/approach – In this research, action research was used to assess and improve a step-by-step guideline. The guideline's conceptual design is based on stakeholder analysis results from those involved in developing urban logistics scenarios and feedback from potential users. A two-round process of application and refinement was conducted to evaluate and enhance the guideline's initial version.

Findings – The guidelines still demand an advanced skill level in simulation modelling, rendering them less effective for the intended audience. However, they have proven beneficial in a simulation course for students, emphasising the importance of developing accurate conceptual models and the need for careful implementation.

Originality/value – This paper introduces a step-by-step guideline designed to tackle challenges in modelling urban logistics scenarios using SUMO simulation software. The guideline's effectiveness was tested and enhanced through experiments involving diverse groups of students, varying in their experience with simulation modelling. This approach demonstrates the guideline's applicability and adaptability across different skill levels.

Keywords Decision-making, Action research, Urban logistics, Simulation modelling

Paper type Research paper

Introduction and background

According to Eurostat only 20.1% of the population lived in rural areas in 2018, whilst 70.9% resided in cities, towns, or suburbs (Eurostat, 2020). The pollution and greenhouse gas (GHG) emissions from traffic considerably impact the quality of life (Hai *et al.*, 2020). As a result, cities worldwide have introduced strategies over past decades to enhance the well-being of

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their residents. A common approach amongst European cities is the adoption of Sustainable Urban Mobility Plans (SUMPs) (Eltis, 2023). SUMPs address all types of transport, tackling intricate challenges from a policy standpoint (Eltis, 2023). Additionally, advancements in creating guidelines for sustainable urban transport can be seen in the extensions of SUMPs, notably in the emergence of Sustainable Urban Logistics Plans (SULP) targeting goods transport (Matusiewicz, 2019). Properly implemented SULP concepts, if they achieve user acceptance, can positively influence urban sustainability. Another trend observed in recent years is cities' efforts to boost local production (Brand Eins, 2016; Busch *et al.*, 2020). Prior research indicates that conflicts arise due to the varying needs and objectives of stakeholders involved in developing urban transport and mobility solutions (Anand *et al.*, 2012; Hauge *et al.*, 2021). These conflicts can be challenging to resolve. Participatory methods have been found effective in addressing urban mobility challenges (Kahila-Tani *et al.*, 2016; Kornevs *et al.*, 2019; Halbe *et al.*, 2020).

Such methods allow all stakeholders to take an active role in the decision-making process. This increases the likelihood of acceptance of the final agreed solution, as participants can reflect upon and better understand the different needs of other participants. However, if the complexity level increases, or if multiple decision levels influence the outcome, even a participatory model might become overly complicated and may need simplification. With this in mind, within a European Union (EU) research project, we embarked on a systematic effort to identify suitable frameworks (Hauge *et al.*, 2021) that meet the demand for a collaborative decision support framework. This framework should be flexible, scalable and replicable, adapting to prevailing decision levels and contexts (Brusselaers *et al.*, 2021). Unable to identify a pre-existing framework, holistic decision support framework was developed (Hauge *et al.*, 2021). For participatory modelling and simulations, this framework must be implemented in a software tool. Numerous simulation tools are utilised for modelling, simulation and optimisation of transport operations. We assessed various tools based on user requirements and Simulation of Urban MObility (SUMO) was chosen due to specific criteria (HUPMOBILE, 2021) and our experience using SUMO in participatory simulations in other cities (Baalsrud Hauge *et al.*, 2016; Raghothama *et al.*, 2022).

A generic simulation model using SUMO was introduced to enhance understanding of how various factors and different decision levels could support the realisation of a specific SUMP (Singh *et al.*, 2022a, b). The objective was to deliver a multi-actor-based SUMP/SULP scenario model, primarily for urban and peri-urban areas. The target audiences are authorities, infrastructure providers, companies and transport operators both within and surrounding the city. This allows them to utilise various simulation scenarios to discuss the impact of transport-related decisions on all urban area stakeholders (HUPMOBILE, 2021). SUMO is an open-source traffic simulation tool, comprising a discrete-time simulation engine and support libraries for network map importing, traffic demand modelling and simulation result analysis (Behrisch *et al.*, 2011; Krajzewicz *et al.*, 2012). It is widely employed for modelling and simulating traffic flow and is also utilised in testing and validating autonomous vehicles (Haddouch *et al.*, 2018; Kusari *et al.*, 2022). Our perceived advantage of using SUMO for SUMP/SULP simulations is its capacity to empower city stakeholders to craft relevant, local simulations. This helps investigate the potential impacts of transport solution changes on other stakeholders and gauge potential environmental effects.

We envisaged that this combination would enhance understanding and heighten stakeholder awareness and involvement aiding in assessing the impact of policy regulations at various levels. However, every city is unique and therefore need its own city/area model. We had assumed that the existing scenarios and framework descriptions would suffice for follower cities with analogous challenges to implement their own scenarios. We were proven, and to avoid failing the project objective, the project consortium explored potential solutions. This research analyses the diverse challenges users confront across planning and design stages when developing participatory simulation models for cities. It unveils the inherent issues preventing field experts from fully leveraging the capabilities of SUMO. Additionally, evaluating current methodologies reveals the strengths and weaknesses of various approaches, guiding the optimal application of participatory simulation to address these challenges. Thirdly, our presented case studies highlight the varied user groups and the pressing need for further blueprint development. The result was an initial draft of step-by-step guidelines (HUPMOBILE, 2022). The guidelines required subsequent testing and evaluation for usability and user-friendliness. This paper delves into the assessment process of these guidelines, exploring challenges in transferring simulation guidelines and discussing the evaluation results for parts of the guideline as assessed by different user groups.

Literature review

The topic of this article is based on the experience we had using SUMO for participatory modelling. The validation of the modelling approach by practitioners knowledgeable in various simulation software types was positive, whilst the challenges in its practical usage for field experts with limited simulation modelling expertise proved to be low (HUPMOBILE, 2021). SUMO, as an open-source simulation software, has been available since 2001 and has frequently been utilised in academic projects. In order to compare our experience in the project with challenges reported in existing literature, a systematic literature review (Tranfield *et al.*, 2003) was carried out in July 2023 using SCOPUS with search string "TITLE-ABS-KEY (*sumo AND modelling) AND PUBYEAR >2013". We selected the last 10 years since the software is continuously being improved and extended.

This resulted in 425 entries on SCOPUS. A quick screening of the keywords, titles and abstracts showed that many entries were not relevant, so we narrowed our search to articles also including "LIMIT-TO (EXACTKEYWORD, "Urban Mobility") OR LIMIT-TO (EXACTKEYWORD, "Urban Transportation") OR LIMIT-TO (EXACTKEYWORD, "Smart city") OR LIMIT-TO (EXACTKEYWORD, "Simulation Of Urban MObility")". This resulted in a final list of 32 articles. Out of the 32 entries eight were excluded because they were not relevant for simulation of transport, logistics or mobility solutions. Most of those eight focussed on simulation of the communication networks required for operating smart city solutions. Two entries were excluded because we could not access the full manuscript.

Most of the relevant papers focus on presenting the capability and suitability of the SUMO software for simulating different urban mobility challenges, such as traffic light optimisation and environmental impact simulation. The challenges addressed are mostly related to the dataset, incorporation of historical data, prediction accuracy, and the advantages of sensor systems for collecting necessary data (Abidin *et al.*, 2015; Ilarri *et al.*, 2022; Rapelli *et al.*, 2022; Shokrolah Shirazi, Chang and Tayeb, 2022). Few directly mention challenges in developing SUMO models for field experts. Yet, Rapelli *et al.* (2022) mention the lack of full-scale models whilst (Rundel and De Amicis, 2023) reports the lack of usability study. Only one article discusses the challenges in modelling of intelligent traffic management systems as such (Akhter *et al.*, 2019).

Furthermore, another challenge is associated with using federated simulations and visualisations. The visualisation possibilities of traffic simulations to overcome challenges in heavyweight simulations of city information models have been explored (Rundel and De Amicis, 2023). They use a combination of SUMO and Unity to provide a lightweight solution but note that this work lacks usability and user requirement studies. According to our experience using such federated platforms for urban mobility solutions, the modelling and requirements analysis are very time-consuming and necessitate extensive skills in simulation modelling, as well as experienced field experts for the validation Zhao *et al.* (2022)

presents work on how to use federated platforms for overcoming the challenge of not having the possibility to collect real-world data.

A check of the authors of the 32 identified papers revealed that all papers had at least one simulation expert and computer scientist. Since we did not find reported articles only written by field experts of urban mobility and transport solutions in the literature review, we cannot conclude that the lack of full-scale models reported by (Rapelli *et al.*, 2022) is caused by their difficulties using SUMO as a modelling tool, but a Google search showed that more practical oriented texts and tutorial mostly show very simple examples that are easy to make without much programming skills, whilst the more advanced ones all require at least the knowledge of applying and changing scripts.

To encapsulate, our literature review has underscored a distinct gap between readily available, simplified SUMO models and the more intricate ones, which demand a higher level of technical expertise. This disparity raises significant questions about the accessibility and usability of SUMO tools for field experts and urban planners who might lack advanced programming skills. The core themes of this paper aim to bridge this evident chasm, bringing the technical world of SUMO closer to the hands-on realities of urban mobility and transport solutions.

Our findings hold paramount implications for a wide range of stakeholders. For policymakers, the clear demarcation between simple and complex SUMO models underscores the need for more user-friendly and intermediate tools that don't compromise on capability. City planners and urban mobility experts must advocate for training sessions that bridge the knowledge gap, ensuring they can leverage advanced SUMO capabilities without delving deep into programming. Additionally, companies and entities developing these tools might consider collaborations with field experts to co-design more intuitive interfaces and tutorials. By doing so, we can ensure a holistic and informed approach to urban planning and mobility solutions that benefit from both expert intuition and advanced simulation capabilities.

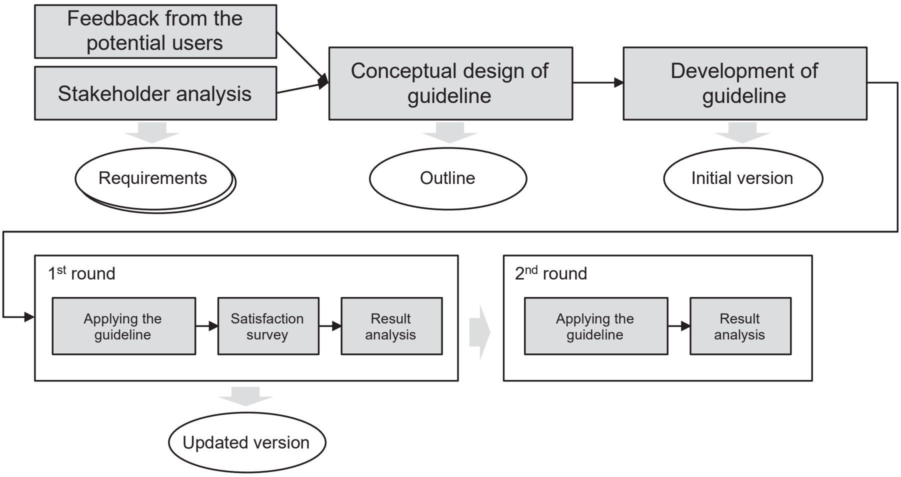
Method

For this study, we employed an action research approach to assess and refine a step-by-step guideline. The conceptual design of the guideline stemmed from the results of a stakeholder analysis, which identified individuals involved in developing urban logistics scenarios, combined with feedback from potential users (HUPMOBILE, 2022). We executed two rounds of application and refinement to evaluate and enhance the guideline's initial version. In the first round, the guideline was introduced and applied to a simulation modelling case. Following this, we conducted a satisfaction survey and analysed the results. Finally, the revised version of the guideline was introduced to a different group of simulation modelling users, and the results were subsequently analysed.

Figure 1 illustrates the design and development process of the step-by-step guideline discussed in this paper. The first round involved Master's level students as the user group, and the satisfaction survey included several questions. This survey was administered anonymously online immediately after the course. For the second round, a distinct user group from an online simulation and modelling course was engaged. This group comprised individuals from the urban logistics industry, public authorities and PhD education programmes. This group undertook a project task utilising our recommended guideline.

Research questions and challenges in urban logistics modelling

The anticipation of multimodal transportation services to significantly impact global market logistics systems (Rondinelli and Berry, 2000) introduced a layer of complexity to the existing logistics problems, rendering decision-making more intricate. The addition of concepts like



Source(s): Author's own work

Figure 1.
Design and development process of the guideline

SULP and SUMP further heightened this complexity. Given this backdrop, a pressing question arises:

RQ1. What are the primary challenges faced when modelling urban logistics scenarios using the SUMO simulation software?

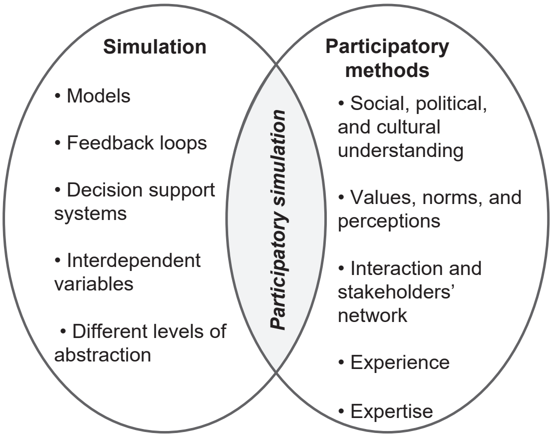
Success in SUMP/SULP planning hinges on stakeholders' understanding of the inherent problems, coupled with a grasp of the needs, requirements and contributions of their counterparts. Participatory modelling emerges as a potential solution, bridging understanding gaps (Raghothama and Meijer, 2015; Kornevs *et al.*, 2019) and albeit with limitations, fostering governance transitions vital for SUMP/SULP's successful implementation (Halbe *et al.*, 2020; Dametto *et al.*, 2022).

Kornevs and other researchers emphasise the utility of models to emulate real-world scenarios, involving actual participants in experiential learning, solution prototyping, policy testing and facilitating system changes (Kornevs *et al.*, 2019). This perspective is visualised in Figure 2 below.

Yet, the task of meticulously crafting these simulation scenarios, tailored for participatory design, is daunting. It mandates a nuanced understanding of the urban landscape, bolstered by adept simulation modelling prowess (Raghothama and Meijer, 2015; Singh *et al.*, 2021). Challenges manifest in requirement definition (Wiesner *et al.*, 2015), simulation model granularity decision-making (Leavell, 2020) and data identification (Black, 1981). Our endeavour, reflected in the introduced multi-level production logistics urban mobility framework and simulation model blueprints, was to alleviate these challenges. However, an inherent research question surfaces.

RQ2. How effective is the step-by-step guideline in addressing these challenges and enhancing the modelling process for users spanning different experience levels?

Our preliminary approach, undertaken by a consortium of simulation and domain experts, displayed promise, yielding adaptable scenarios. But the real test surfaced when cities, devoid of this consortium's expertise, embarked on developing their scenarios.



Source(s): Kornevs *et al.* (2019)

Figure 2.
The role of participatory simulation

Their struggles spotlighted the steep learning curve associated with the chosen open-source simulation tool, necessitating both scripting acumen and a profound model comprehension. This revelation steered our efforts towards crafting a comprehensive guideline, culminating in the project result (INTERREG Baltic Sea Region Programme, 2019). Yet, a residual question lingered:

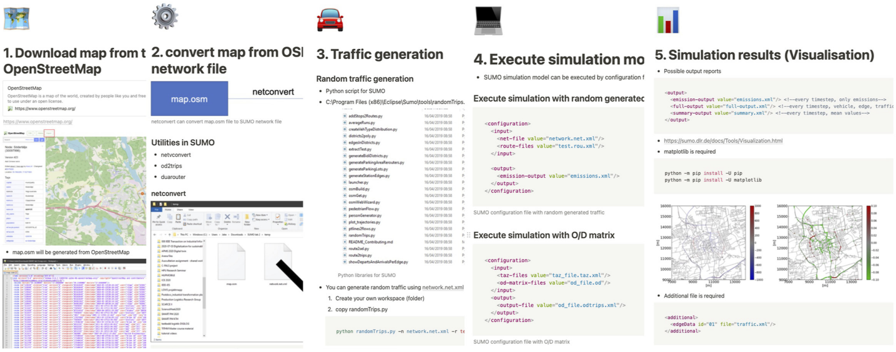
RQ3. Based on feedback from experiments and coursework applications, what refinements are essential to render the guideline universally accessible and yield greater impact?

With these questions laid out, the ensuing sections dissect the guideline in question, aiming to ascertain its potential as a transformative tool in urban logistics simulation.

The step-by-step guideline for urban logistics: a problem solver or a work-in-progress?

The guideline we present is envisaged as a tool to carve out a multimodal optimisation landscape for transport flows. By aiding decision-makers in pinpointing optimised transport flows and earmarking transportation modalities apt for each node, it holds promise. Users are offered the flexibility to either repurpose their existing simulation models into a multimodal optimisation model or venture to create an entirely new one.

Included within the guideline is a case example showcasing the conversion of an existing simulation model into a multimodal optimisation model. This case revolves around a new harbour area in a port city. The primary objective is to determine the optimal parking solutions, taking various environmental factors into account. The guideline outlines several procedures for modifying the characteristics of roads and vehicles in SUMO. For this scenario, users must impose street restrictions to prevent large trucks from accessing the city centre. Users should also highlight key performance indicators (KPIs), such as total GHG emissions, waiting times and more. Another section of the guideline offers comprehensive instructions for crafting a new simulation model from the ground up. Figure 3 delineates the step-by-step process to construct a new simulation model. Developed within an interactive web environment, this document ensures users can effortlessly navigate the steps and embed supplementary links as needed.



Note(s): (1) Export a map from the OpenStreetMap (OSM); (2) Convert the map from OSM to SUMO network file; (3) Generate traffic flows; (4) Execute the simulation model; (5) Analyse and visualise simulation results

Source(s): Author's own work

Figure 3. Step-by-step guideline – build a new model from scratch

The guidelines were showcased to both the consortium and attendees of the final project conference. It was received as a promising advancement towards broader adoption. However, due to time constraints, follower cities couldn't thoroughly assess the guidelines. As a result, doubts lingered about whether the guidelines could adequately facilitate the learning process. To determine if the initial version met the user requirements for an intuitive, self-guided approach to constructing simulation scenarios, we opted to trial the guidelines with diverse participant groups: typically, full-time engineering students at the master's level (first round in Figure 1) and lifelong learning (LLL) attendees enrolled in a modular course on new urban mobility trends (second round in Figure 1). The ensuing chapter describes the experimental set-up in greater detail.

Experimental set-up

The user group in the first round comprises students from the Master's programme in Sustainable Production Development. This programme offers cutting-edge education in the design and development of production systems. It focusses on topics such as production management, production logistics and industrial dependability. Whilst the programme aims to hone practical hands-on skills, it also seeks to provide a broad overview of production systems interwoven with sustainable development concepts. As a result, many students in this programme lack experience in computer programming and general coding. However, they all possess a foundational understanding of simulation modelling, albeit primarily theoretical. To address this, one of the courses in the programme emphasises enhancing students' practical abilities in simulation, programming and statistical analysis. During the course, students familiarise themselves with various simulation tools in lab sessions. Some of these tools are commercial software with extensive documentation and tutorials, but students also engage with open-source tools. The course is structured in two segments: theoretical lectures and a practical component that includes lab sessions and project work.

However, using SUMO can be challenging without external resources like guidelines. To tackle this, the SUMO lab sessions were bifurcated into two sections: basic and advanced. In the basic segment, students learn about data formats, input modelling and output analysis through examples. For the advanced segment, students receive preparatory tasks complemented by guidelines, utilising the latter to address specified problems during the lab session.

The second user group consisted of participants from the EIT New Urban Mobility LLL programme. This group had a more varied background compared to the first. Given the programme's urban mobility focus, participants were more familiar with traffic simulation tools. This programme targeted employees from local authorities and industries, but also welcomed PhD students from the participating universities as well as PhD students from urban mobility-centric programmes and professionals with profound domain knowledge. Thus, we anticipated that this group would more closely resemble the original target audience of the research project. Regardless of their backgrounds, proficiency in traffic analysis, logistics planning and programming remains crucial for using SUMO.

Figure 4 contrasts the experimental set-ups of the first and second rounds. In the first round, there was online preparatory work preceding the lab session and students undertook self-directed learning using tutorials and online resources to grasp the data structures, as well as basic and advanced SUMO features. They received the step-by-step guideline during the second lab session, concluding the SUMO modules. Conversely, the second-round participants had access to the guideline from the module's commencement, paired with the project description. This project was to be finalised by the module's conclusion, six weeks post the project announcement. During this interval, participants were provided with recorded video clips to facilitate understanding of SUMO's data structures, basic and advanced features.

Analysis of the experiment results

The experiments conducted with two distinct student groups had a dual focus. First, we sought to assess and validate the usability of the developed guideline. Second, we aimed to comprehensively investigate the challenges inexperienced users faced with the open-source software, facilitating further refinement of the guidelines. Given the differences between the two student groups, we anticipated varied challenges. This section presents feedback from the first round and assignment submissions from the second. A satisfaction survey, comprised of the following questions, was used to gather feedback on the guideline from the first-round users:

(1) Did you have enough time to follow the lab sessions?

(2) What was the step-by-step guideline used for modifying the SUMO model?

(3) Was the guideline's purpose easily comprehensible?

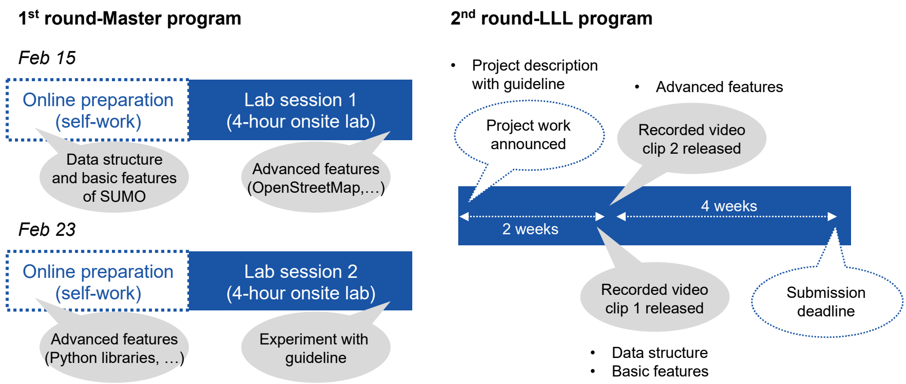


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Figure 4. Experimental set-up comparison between the first and second rounds

(4) Could you discern how the changes would affect the model?

(5) Did this activity align with the course's learning objectives?

(6) Did this exercise enhance your understanding and deepen your knowledge of the learning objectives?

Below are the responses from the first-round participants and Figure 5 depicts the distribution of responses regarding the step-by-step guideline.

(1) Did you have enough time to follow the lab sessions?

- Some instructions, especially in the SUMO labs, were ambiguous. Many complications arose, resulting in sessions taking considerably longer than scheduled.
- SUMO demands more time because of the necessary programming skills.

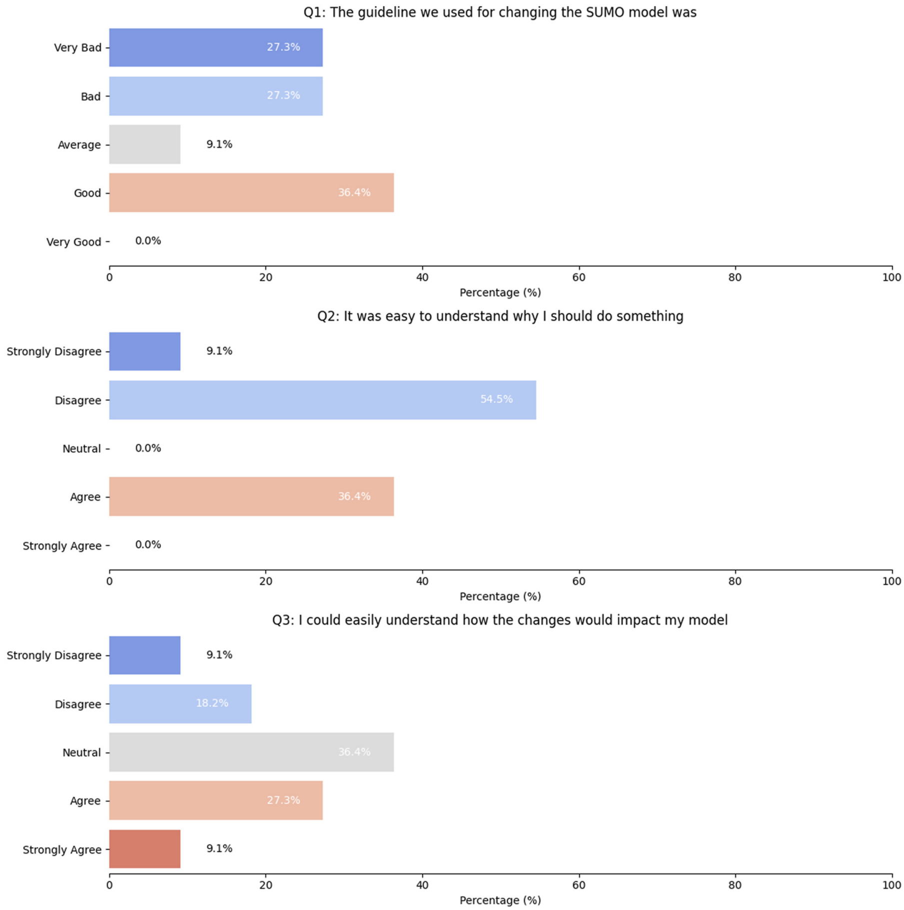

Figure 5. Survey outcomes pertaining to the guideline questions

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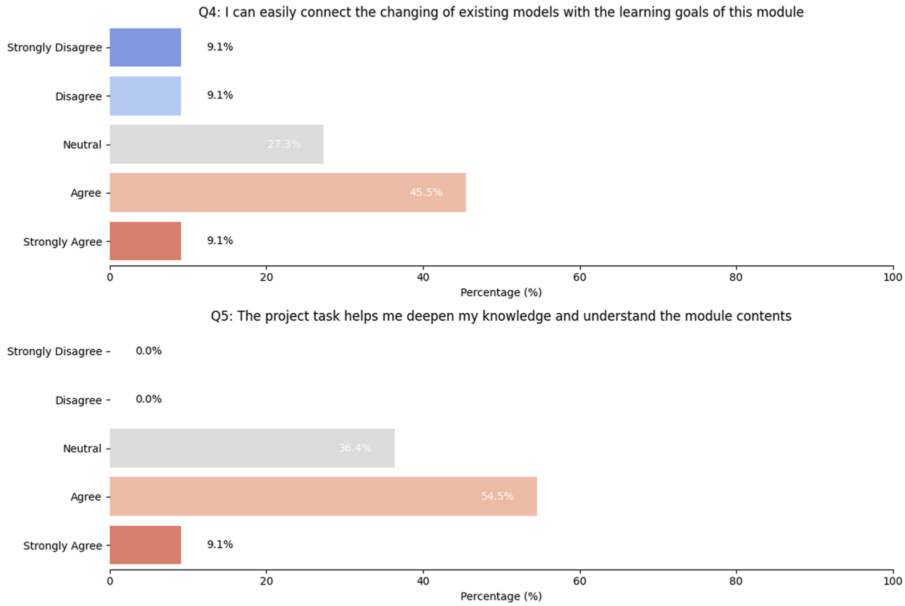

Figure 5.

Source(s): Author's own work

(2) General feedback about the SUMO lab:

- The overall objectives and tasks were difficult to grasp.
- The second lab had scant instructions, making the required steps ambiguous.
- Critical information was absent, and the accompanying video was not lucid.
- The instructions were muddled with significant omissions. Accessing files from NETEDIT (a road network editing tool) would have been simpler than following vague XML instructions.
- Whilst the steps were understandable, almost all participants encountered errors not addressed in the guidelines.

This survey analysis reveals that whilst the guideline is deemed adequate, it is not exceptional, with no top ratings. This indicates a potential for enhancement. The understanding of task purpose is not clear to all participants, with a majority indicating some level of disagreement. This suggests a need for clearer instructions or explanations. Responses about the impact on model understanding are varied, pointing to a user base with diverse abilities or prior knowledge. A tailored instructional approach might be beneficial. However, the majority's ability to connect model changes to learning goals is a positive sign, suggesting the exercises are relevant to the educational objectives. The project tasks are generally seen as beneficial for deepening knowledge, with most participants agreeing. This underlines the project's effectiveness as a learning tool.

Recommendations include refining the guidelines to aim for excellence, clarifying the purposes behind tasks and offering instruction that addresses the varied learning styles and knowledge levels of participants. The alignment of practical tasks with learning goals should continue, affirming their educational relevance. Lastly, it's crucial to communicate any changes based on this feedback, reinforcing the value placed on participant contributions.

The second round diverged from the first in its approach. Whereas the first-round participants hailed from a modelling and simulation course, the second group was from a broader urban mobility service programme. This course zeroed in on contemporary urban mobility technologies, with modelling and simulation being merely one component. Consequently, we didn't anticipate an in-depth knowledge of simulation modelling from them.

Moreover, the pedagogical environment of the second round differed from the first. The initial round was conducted in-person on campus, fostering immediate communication. In contrast, the second round employed a remote learning format, necessitating enhanced communication. Comprehensive video instructions were furnished in advance to mitigate these constraints. Students were allocated ample time to follow the tutorial, acquainting themselves with SUMO for problem-solving. Subsequent to this, they received an assignment solvable via SUMO. Figure 6 excerpts the assignment's description.

In the second round, only a handful of participants successfully completed their assignments. Some of the submissions didn't meet the assessment criteria, resulting in assignment failures. Comments from students who couldn't produce results included statements like, "I couldn't access the requisite instructions for the simulation," and "This is all I could manage in SUMO, having never used it previously." Conversely, students with prior SUMO experience discerned the assignment's intent and produced commendable results. They adeptly identified and employed the appropriate add-on libraries in their assignments for traffic generation, even though these weren't delineated in the guideline.

SUMO, as an open-source simulation tool, offers promising possibilities for advanced simulations in urban transport and mobility solutions. It stands as a robust instrument that can bolster the shift towards environmentally friendly mobility and transport solutions.

This module has focused on fundamentals of future urban mobility solutions. You have heard about **1) stationary, static and dynamic charging, about traffic management**, **2) transport planning** as well as **3) mobility as a service** - all based on including the latest technology developments and industrial/commercial uptake. Some of the approaches are more like a vision of tomorrow, or better in 20 year, but the investment, time to develop and also adapt to our needs takes time. Therefore, **planning is essential**. In the MOOC on SUMO, we have introduced an open-source tool that can help a little, but only **if we ask the right questions and have the right data** (and the forecast needs to fit the future we do not know).

In the project for the module, we aim at developing your competencies in using planning tools and to apply what you have learned. Your task is therefore to use SUMO and to **create your own simulation model from your city**. Please follow the instruction below.

- Select your hometown (if they provide you access to OpenStreetMap) and convert OpenStreetMap to SUMO road network.
- Construct at least three different traffic demands (trip, route, or flow) with at least 10 edges.
- Please run for 5 different vehicles types.
  - At least one needs to be an EV, one bus with planned stops and one a heavy truck.
- Compare the different outputs like fuel consumption, energy usage, GHG emissions.
- Use the functions for traffic lights, and EVs charging.
- Please run the simulation so long that every EV needs to re-charge 4 times (if static/stationary)
- Answer the questions below.
  - How can you model stationary, static and dynamic charging in your simulation?
  - Implement the functions of a traffic management systems as you heard about in the class. How do you need to configure your model?
  - Please discuss the limitation of your model for an application in your city

Source(s): Author's own work

Figure 6. Overview of the SUMO-based assignment

Nevertheless, experiments involving two distinct groups, comprised of students and practitioners, showcased the software's intricate nature. It necessitates not only an in-depth understanding of the mobility and traffic issues but also knowledge on constructing simulation models, grasping the data structure of input/output information and honing programming skills. Specifically, the LLL course, which included many practitioners with a profound understanding of urban transport and mobility, underscored that this software is best suited for simulation specialists. The steep learning curve and the time investment required to develop the necessary skills make it challenging to use for just one specific scenario. A more efficient approach might involve having a simulation expert create the simulation models collaboratively with urban transport and mobility solution planners, who are well-acquainted with the unique challenges and requirements.

Discussion

In this section, we revisit and critically analyse the research questions, informed by our experimental findings and the challenges encountered during the application of our participatory design-based decision support framework.

Originating from our immersion in a research project, we architected a sophisticated multi-criterion, multi-level decision support framework, purposed for urban goods and passenger transport, as well as an array of simulation scenarios utilising the SUMO open software. A quintessential aspect of this endeavour was the participatory design approach, ensuring real-world applicability and stakeholder inclusiveness.

Given the derived insights, we fashioned a tool intended to equip subsequent cities with the capability to tailor and craft novel simulation scenarios suited to their intricate urban fabrics. Nevertheless, this endeavour was met with multifaceted challenges. From intricacies in software installation, exacerbated by internal regulations and computing capabilities, to the pronounced perception of SUMO's complexity. A significant observation was the perceived demand for a holistic foundational knowledge of simulation scenario creation, which posed challenges for domain experts in creating new models, though some modifications to existing scenarios were feasible.

Initial experiments with master's students enrolled in a simulation course, offered illuminating insights. Whilst feedback indicated that the step-by-step guideline adequately mapped to the intended learning outcomes (ILOs), a dichotomy emerged. A considerable 36% asserted the guideline's efficacy in elucidating the rationale behind their actions yet struggles in operationalizing pre-acquired theoretical knowledge were evident. Around 30% showcased prowess in deducing the ramifications of their model tweaks based on the guideline, hinting at challenges in comprehending the foundational simulation model components. Notably, a segment applied the guidelines without a comprehensive understanding of the foundational principles, potentiating the risk of flawed simulation models which, if utilised in urban planning, could lead to misguided decisions.

Following this, a tailored for a diverse audience as detailed in our experimental set-up, underscored the guideline's limited support for novices. Despite participants demonstrating profound comprehension of urban mobility stakeholders and the intricacies of SUMP/SULP implementation, a recurring theme was the struggle to manifest this understanding into functional simulation models within the time constraints. Of note were the exemplary projects emerging from doctoral candidates specialising in simulation.

Reflecting on the outcomes of both experimentations, leads to the conclusion that the current design of guidelines, blueprints and framework may not be optimally streamlined for field experts to effortlessly adapt to their unique city scenarios. The pronounced reliance on advanced simulation modelling capabilities renders the guidelines less accessible for the primary target demographic. However, their merit lies in emphasising the pivotal role of precise conceptual model development and its judicious execution, especially for simulation course students.

Based on the experimental findings, it is apparent that the guideline warrants fine-tuning to better address the practical needs of its users. The distinction in skill levels between novice users and those seasoned in simulation underscores the importance of implementing a layered instructional strategy. The analysis has led to the formulation of essential insights and recommendations, all of which are encapsulated in Figure 7.

(1) *Refinement of step-by-step guidelines:* There is an evident need for more granular, user-friendly guidelines that deconstruct complex processes into manageable steps, thus making the simulation tool more approachable for a broader range of users.

(2) *Integration of theoretical and practical knowledge:* The findings suggest a need for a more cohesive educational structure that aligns theoretical knowledge with its practical application. This alignment would enable users to put academic concepts into practice within the simulation environment effectively.

(3) *Support structures for varied expertise levels:* Recognising the diverse user base, from master's students to field experts, we recommend the creation of differentiated learning pathways and support mechanisms tailored to distinct competency levels.

(4) *Iterative development based on user feedback:* Continuous refinement of the guideline should be based on iterative feedback loops with users to ensure the framework evolves in alignment with user experiences and needs.

(5) *Emphasis on applied learning:* Implementing applied learning sessions, like hands-on workshops and collaborative problem-solving exercises, can foster the direct application of knowledge.

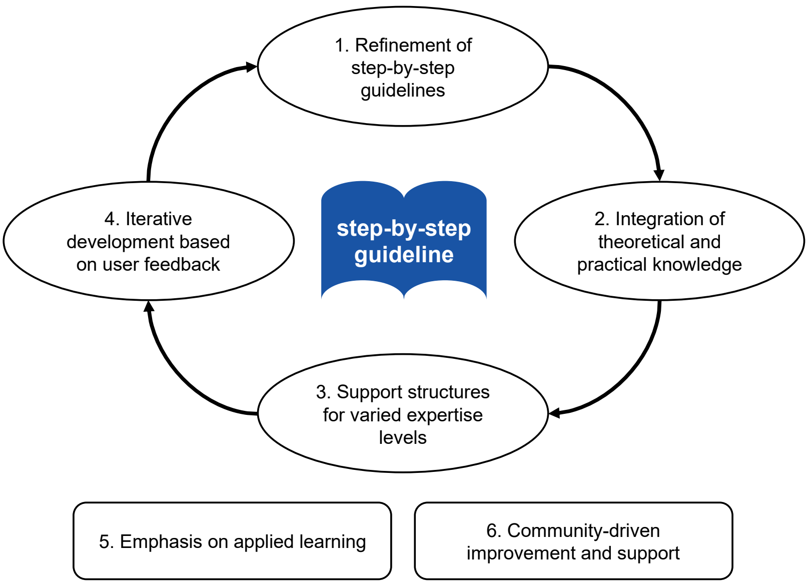

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Figure 7. Key takeaways and actionable recommendations to enhance the step-by-step guideline

(6) *Community-driven improvement and support:* Establishing a community around the simulation tool can facilitate peer-to-peer support, exchange of best practices and collective troubleshooting, thereby enhancing the learning curve for new users.

In conclusion, whilst our participatory design-based decision support framework represents a robust starting point, it is evident that further refinement is required to fully realise its potential. The incorporation of the above recommendations into the framework will enhance its accessibility and efficacy, ensuring that it not only serves the academic community but also becomes a valuable asset for urban logistics practitioners.

Conclusions and future work

This research set forth to demystify the complexities of urban logistics modelling through the SUMO simulation software, culminating in a guideline refined through experimentation and feedback, particularly from diverse student demographics with varying simulation expertise. Our key findings underscore the importance of programming knowledge in leveraging the full potential of our guidelines and highlight areas where further simplification and support could bridge the gap for users with limited coding experience.

The broader impact of our work lies in its potential to inform urban logistics practices, providing a foundational tool that can be adapted to a wide array of urban scenarios. We foresee our guidelines evolving into a dynamic resource for urban planners and policymakers, shaped by ongoing feedback and collaborative development.

Looking ahead, we have charted a clear course for the guideline's enhancement, with reiterations slated for trial in upcoming course offerings. We anticipate sharing the outcomes and a fresh batch of user feedback. To ensure the longevity and adaptability of our work, all project outputs will be maintained and updated online through 2026, with the new guidelines undergoing revisions reflective of the latest student evaluations. In tandem, we are developing supplemental Massive Open Online Courses (MOOCs) to complement the guidelines, enriching the learning experience with multimedia resources and ensuring unfettered access to our blueprints.

Recognising the unique confluence of urban logistics and programming, our future efforts will concentrate on refining the guideline's clarity and ease of use to achieve broader adoption. Our aspiration is to render it an indispensable instrument in urban logistics planning, universally applicable and robust against the test of emerging trends and technologies. In this endeavour, we not only welcome but also depend on the constructive engagement of the academic and practitioner communities, whose contributions will be instrumental in the guideline's ongoing refinement.

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