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Development of a concept for the design of user-friendly simulation models

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Abstract

Products are becoming more individualized and complex, with shorter life cycles, posing significant challenges for companies. Material flow simulations help to model, analyze, and optimize manufacturing processes without expensive, time-consuming real-world tests. However, they are often complex and reserved for experts, limiting broader use. This paper aims to develop user-friendly simulation models. Based on a collaboration with an industrial partner, the research involved several practical and theoretical steps and evaluations. First, an existing simulation model was analyzed in order to identify potential improvements in terms of user-friendliness. The focus was on data input and visualization. Improvements were implemented and tested, demonstrating that the initial requirements were largely met. A generally applicable concept for user-friendly simulation software was then developed, consisting of a four-stage procedure with corresponding design rules. This practical approach outlines concrete steps to make simulation models accessible to less experienced users, enhancing efficiency.

Keywords: Material flow simulation; Usability; User-friendliness

1. Motivation and background

The rapid development and change of production processes is a major challenge for companies. In order to remain competitive, agile adjustments and optimizations are required along the entire value chain [1]. A key approach to overcoming these challenges is material flow simulation, which replaces time-consuming and expensive tests on real systems [2]. In many cases, not only individual processes but entire production systems with a wide variety of processes are modeled [3]. The more complex the production systems is, the more complex the simulation model becomes. In practice, the operation of such models are complex and require specialized knowledge with extensive training. Developing user-friendly simulation models is, therefore, crucial in order to take full advantage of simulation technologies in any organization [4]. Intuitive and accessible interfaces enable less experienced employees to familiarize themselves quickly and use the models independently. However, although there are a large number of simulation modeling techniques, there is a significant gap in accessibility for non-experts [5].

Therefore, it is necessary to develop general concepts for the design of user-friendly simulation models to cast an alternative to automated simulation model generation and make use of humans deep understanding [6]. This work aims to develop a concept for the design of user-friendly simulation models.

2. State of the art

This section provides the foundation for a common understanding and explains the related work. It should also show how user-friendliness is already applied in simulation models and where there is a need for research.

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2.1. Basics of usability in material flow simulation

User-friendliness correlates with ergonomics. While hardware ergonomics aims to promote the physical health and comfort of users, the focus of software ergonomics is on creating an optimal user interface (UI). These should be intuitive and simple to increase user satisfaction and efficiency [7]. The term *Usability* originates from the field of human-computer interaction (HCI) and is an important concept in the design of products and user interfaces in recent decades due to the increasing multi-functionality of systems [8]. However, usability is not a discipline like ergonomics, but a desired quality condition of a technical system [8].

According to Heinecke [9], the way users perceive the system has an important role in user-friendliness, as the human brain processes the stimuli it receives and proceeds according to the Gestalt laws defined by Wertheimer [10]:

- The law of proximity states that elements that are closer to each other are perceived as belonging together.
- The law of similarity states that elements that are similar in their properties are perceived as belonging together.
- The law of closure states that people complete incomplete patterns or shapes in order to create a coherent image.
- The law of continuity states that people interpret lines and shapes so that they run in a flowing, continuous manner.

This knowledge helps to derive design tips for systems. Visual highlights can direct attention and make relevant information visible more quickly. However, they should not distract from the work. The grouping of input elements can help to clarify relationships. In addition, user interfaces should be limited to the most important elements in order to prevent users from being distracted. Therefore, when designing the system, care must be taken to ensure that it is easy to concentrate on a task after an interruption. [8]

Following [11], visual descriptions are much easier for people to understand than verbal descriptions. When designing systems and interfaces, visual descriptions should therefore be used in a targeted manner. However, a graphical representation alone does not make a system user-friendly. The presentation of the displayed object plays a central role and the objects should be shown in a way that it can be intuitively recognized by the user, as people try to compare the displayed object with a *mental image* [8]. The more unusual and larger the rotation and viewing angle of an object compared to the mental image is, the longer it takes to identify the object [8].

2.2. Usability-evaluation

There are various methods for determining whether a system or method is user-friendly. These include analytical or heuristic evaluation procedures, but also various usability tests [12]. The decisive factor is that the benefit of this method is greater than the use of alternative methods [13]. As a guideline, Nielsen [14] developed on the basis of 249 usability problems ten general heuristics:

1. The system should always provide users with feedback on its current status and the progress of their actions.
2. The user interface should use terms and concepts that users know from the real world to avoid misunderstandings.
3. Users should be given the opportunity to undo mistakes and easily return to the starting point.
4. The user interface should be consistent, both in terms of terminology and in terms of layout and design.
5. The system should be designed in such a way that users cannot make mistakes or correct them easily.
6. Information, options and functions should be visible instead of users having to remember them.
7. The system should be able to be used efficiently by both inexperienced and experienced users.
8. The user interface should avoid superfluous information or elements and be aesthetically pleasing.
9. If necessary, the system should provide assistance and documentation to help users identify and resolve errors.
10. If documentation is necessary, it should be easy to find, understandable and useful.

Derived from these concepts, usability engineering describes the systematic process of designing and developing user interfaces and interactive systems to ensure that they are user-friendly and effective [15].

2.3. Existing approaches

Several studies are already conducted within the context of simulation tools. Law [16] stresses the importance of user-friendly interfaces in simulation tools, noting the prevalence of run-time licenses that limit model logic changes. He highlights Microsoft Excel with VBA for its widespread accessibility and familiar interface, enabling intuitive controls like buttons and menus to manage and store simulation parameters effectively.

Rutle et al. [17] propose role-based usability in simulation, where experts develop models and simulation logic while users interact through simplified interfaces. They recommend graphical languages and symbols for intuitive parameter input to enhance operational focus and clarity.

Schumann [18] demonstrates interface design strategies in AnyLogic, integrating simplified control panels within simulation models. His approach includes categorized parameters, tooltips for function explanations, and various input methods like buttons, dropdowns, and validated free-text fields to ensure accurate data entry and usability.

Kuljis [19] critiques existing simulation systems for prioritizing visual aspects over robust data input mechanisms, advocating for improved validation and format independence in user interfaces to enhance usability and data integrity.

Additionally, the U.S. Department of Health and Human [20] outlines web design principles, emphasizing usability and accessibility standards, which can inform user-friendly interface development particularly in data input interfaces.

2.4. Example models

It can be shown that there is no scientific approach on how to design user-friendly simulation models. However, there are examples of industrial projects in which at least partial user-friendliness has been implemented. One example is the software Cura from UltiMaker [21]. Cura simplifies model preparation and optimization by offering an intuitive interface that supports diverse user needs. It provides visual previews of print outcomes, aiding users in evaluating designs and troubleshooting potential printing issues.

Another example is the simulation tool of Fraunhofer Institute for Building Physics [22] named PALM-4U, a user-friendly simulation model for urban climate planning. PALM-4U facilitates city officials in identifying heat stress areas and testing mitigation strategies through an automated model setup process based on map data and 3D models. Its intuitive menu allows users to adjust building properties such as wall color and facade greening via dropdown menus, with changes reflected instantly in the simulation model. Post-simulation, results can be visualized through heatmaps, enhancing decision-making.

2.5. Research deficit

It can be seen that there are already some implementations of user-friendliness. However, there is still no general reference guide that can be used to summarize how user-friendly models should be created. There are few complex simulation models that are designed for inexperienced users. User-friendliness is evident in the areas of data input, parameter visualization and presentation of results. In each of these areas, there is a lack of instructions specifically adapted to simulation. Therefore, the objective is to develop guidelines for improving user-friendliness in simulation models, focusing on data input and parameter visualization.

3. Case Study

The object of the study was an existing model of an industry partner. Typical interaction scenarios with the model were examined to define personas and optimized for user-friendliness. The user roles were segmented, whereby four main roles were defined: viewer, user, experts and trainer. Viewers interpret simulation results and analyze graphics without the need of modelling skills. Users are active participants who modify parameters and run scenarios, requiring a basic understanding of the models. Experts develop complex models, while possessing a deep knowledge of simulation methods. Trainers educate other users on applying simulation models and impart knowledge.

3.1. Identifying personas

This study aims to support viewers and users through more user-friendly models and simple input interfaces, enabling them to work more independently. Based on interviews with the industry partner, three relevant personas were defined, representing diverse skills and objectives and real-world situations were outlined that the personas would encounter based on their daily tasks.

The planner modifies the simulation in several ways. They allocate the operator tasks at stations to adjust personnel roles for material handling and processing. They fine-tune process variables like times, scrap rates, and repair durations to accurately reflect real-world conditions. The planner updates employee travel routes to align with changes in the production layout. They are able to add or remove stations or split processes to optimize the workflow or enhance the production flow by decoupling stations using buffers or conveyors.

The supervisor observes production processes with the help of the simulation model and interprets key metrics, to quickly react on performance data whenever changes occur.

The student learns and understands production processes by using the model to study the production line. They observe the various production steps and examine the overall layout, gaining insights into the production system.

3.2. Analyzation of the previous model

After defining the persona, the existing simulation model and established processes of the industry partner were analyzed for user-friendliness based on predefined scenarios. Employees identified known issues, and inspection methods like walkthroughs revealing application problems. The model and interface were evaluated using heuristics from Nielsen [14], uncovering two main issues: the model's complexity and the unintuitive interface. The model was extensive and difficult to navigate, with stations that are often highly abstracted and differing significantly from their real-world counterparts. This abstraction made understanding processes and navigating the model challenging, especially for new users. The tripartite station setup (load, work, unload) resulted in stations looking identical, complicating the distinction between them. Misplacement of stations and simplified representation of produced parts further increased the user confusion.

Furthermore, the interface was cluttered and integrated directly into the simulation model, lacking a structured menu for parameter settings. The continuous expansion led to complex and overloaded controls, where values and KPIs were displayed alongside methods and parameter lists. There was also limited documentation, so users had to know the specific locations for variable settings as well as the current parameter settings beforehand.

4. Results

The requirements were first derived from the case study, and then implemented in the model. Afterwards, some solutions were implemented directly in the existing model. For others, an improved user interface was developed.

4.1. Requirement for an improved model

Based on workshops and subsequent analysis, several requirements have been identified for the revised simulation model. The simulation model must prioritize a user-centric design, catering primarily to viewers and users with minimal simulation experience by providing a detailed and accessible representation of production processes, goods, and equipment. It must ensure traceability and reproducibility, with input values clearly influencing the model for accurate interpretation and consistent results. The user interface should be simple, and intuitive, allowing for quick modifications of simulation parameters, with clear navigation, labels, and logically arranged controls. Efficiency is key, aiming for minimal steps for parameter changes, reduced loading times, and swift simulation execution. Furthermore, detailed visualization of processes is essential for user comprehension, with the model depicting the layout, stations, and products accurately for immediate recognition. Error prevention mechanisms must be in place, informing users about invalid inputs and ensuring the simulation only starts with valid parameters. The simulation model needs also be compatible with Siemens' Plant Simulation software, used by the industry partner, and adaptable to other simulation models within this environment for broader application. The evaluation process for transforming the model into a user-friendly version involved iterative steps across multiple sprints. User scenarios were defined and optimized, with ideas collected and evaluated for usability enhancements before being prototyped. This process was carried out separately for model visualization and interface improvement scenarios. Whereas, changes in visualization were directly implemented and evaluated by different users.

4.2. Changes in the simulation model

Production hall elements such as columns and walls were added to facilitate quicker orientation for users by integrating distinctive landmarks, like entrances and central workstations. This led to improved recognizability and an intuitive understanding of the production environment. Decorative elements were added to highlight certain areas as a clear point of reference. These adjustments resulted in a more precise depiction of walkways, which in turn improved the accuracy of walking times in the simulation. In addition, workpieces, load carriers and transport carts have been simulated more realistically, which makes it easier for new users in particular to understand the process and enables a more intuitive assessment of the number and handling of workpieces.

4.3. Changes to the user interface

The user interface of the simulation underwent substantial enhancements to improve usability and streamline the management of recurring scenarios, as seen in Fig. 1. By using Microsoft Excel, the new UI takes advantage of Excel's prototyping capabilities and its integration with Plant Simulation, allowing simple data import and manipulation.

The main menu of the new UI features multiple fields where users can set system parameters, buffer sizes, employee assignments, and process variables, providing a straightforward way to configure essential simulation settings and obtain a quick overview of key configurations. Light green input fields indicate editable areas, reducing the likelihood of errors and allowing for easy adjustments even after periods of inactivity. Navigation through the UI is facilitated by buttons that enable users to switch between pages, save inputs, and launch the simulation program, making it more user-friendly and efficient. The input fields are designed to accept a set range of values, with instant validation to prevent errors that might only be detected during the simulation's execution, thereby ensuring data accuracy.

The detailed process parameters menu allows users to configure specific station parameters such as worker assignments, task times, and machine availability, enabling precise customization of the simulation. The intuitive layout and consistent logic of these menus help users understand and modify tasks easily. Additionally, the UI allows for flexible worker assignment and task sequencing through the worker loop configuration, which enables users to define task orders for each worker, enhancing the simulation's representation of work schedules and process flows.

These UI improvements have significantly enhanced the management of simulation scenarios. Users can now easily change employee assignments, adjust process variables, and modify walking paths, making it easier to simulate different operational scenarios and understand their impacts. The ability to deactivate stations and customize shift plans has improved the flexibility and relevance of the simulations, leading to a more effective and user-friendly simulation environment.

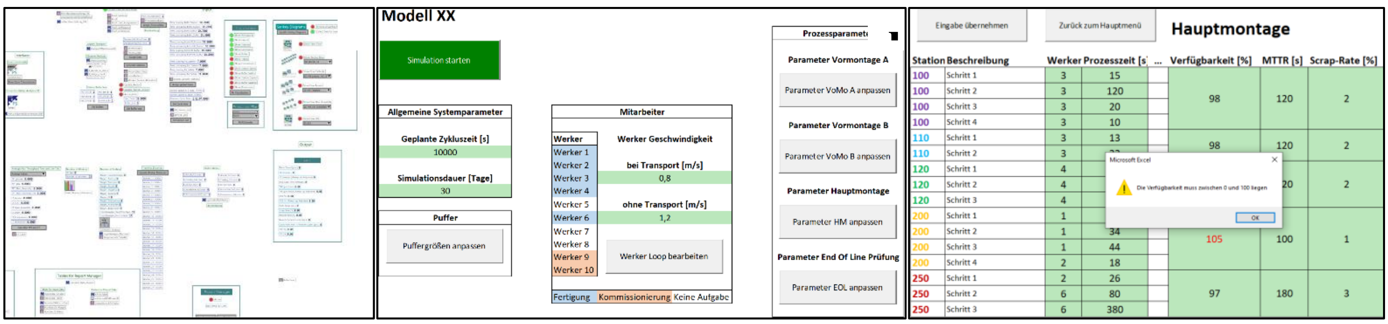

Fig. 1 (a) previous UI; (b) main window of the revised UI; (c) subpage of the revised UI for machine values of the main assembly

5. Evaluation of the user interface

To assess usability, an evaluation was conducted between the original model from the industry partner and the revised model. Test subjects were tasked with locating specific objects on the user interfaces, and the time taken to find these objects was recorded. Eye-tracking was used to analyze which areas the subjects focused at while looking for these objects. The resulting heatmaps, shown in Fig. 2, indicate where the attention of the testers was focused. The tests involved 16 participants who had no prior exposure to the simulation model. For comparability, the eye-tracking data focused on the interval between 0.5 and 10 seconds, regardless of the actual time taken to find the objects. The lower limit of 0.5 seconds was set because participants initially viewed a black screen, which often directed their gaze to the center, creating an unwanted heat zone. The upper limit of 10 seconds was chosen as almost all participants found the objects on the new UI within this time frame, whereas it took significantly longer on the original model. Recording for longer periods would have made the heatmaps less comparable.

In the first test, participants were asked to find the "Number of Worker" variable and the "ProcessData" list on original interface in Fig. 2a. On the new UI, displayed in Fig. 2b, they had to locate the field displaying the number of workers and the button leading to the main assembly parameters menu. The heatmaps indicated that on the redesigned UI, the objects were identified more directly, with large hotspots indicating focused attention. On the original interface, the gaze wandered more, and there were no distinct hotspots. Time measurements confirmed these observations. The median time to find both objects on the original interface was 84 seconds, compared to just 7 seconds on the new UI. Additionally, the variance in search times was much greater for the original interface, ranging from 62 to 116 seconds between the first and third quartiles. In contrast, the new UI showed a much narrower range between 5 and 8 seconds

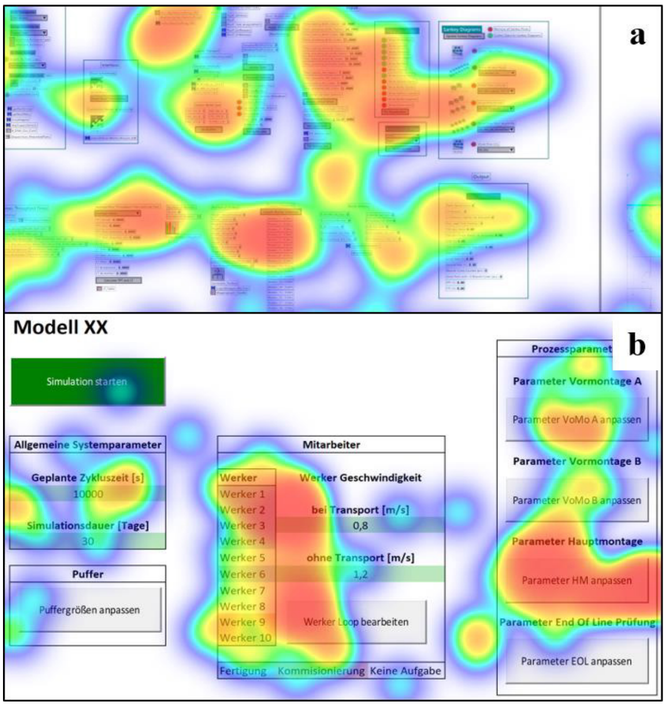

Fig. 2 eye tracking study (a) previous UI; (b) new UI

In the second test, participants were instructed to identify a potential error in the "ProcessData" list on the old user interface and in the main assembly parameters menu on the new UI. The participants had to specify the erroneous parameter and the corresponding station for both interfaces. The eye-tracking analysis showed clear hotspots around the sought objects in the new UI, whereas no distinct hotspots were observed in the original interface. Time measurements confirmed these findings: the median time to locate the error in the old UI was 49 seconds, with a range of 36 to 65 seconds. In contrast, the new UI reduces this time to a median of 5 seconds, with a much narrower range of 4 to 6 seconds.

6. General approach

The general approach is the result of the case study and the evaluation. A general procedure for the creation of user-friendly models can be described, as well as generally applicable rules for the UI and the model. Test 1:

6.1. General procedure

The own procedure for the improvement of the existing model can now be summarized as a generally applicable approach for the optimization of simulation models. Similar to Sarodnick and Brau [5] usability engineering approach, it consists of four phases:

(1) Analysis Phase: Collection and analysis of basic information, interviews with users to identify needs and deficits. Creation of personas and scenarios that serve as requirements.

(2) Concept Phase: Definition of the project structure and collection of implementation ideas. Outlining and evaluating approaches for implementation.

(3) Development Phase: Testing and adapting the model as well as developing and optimizing the user interface based on prototypes and user feedback.

(4) Implementation Phase: System finalization and fixing of remaining issues, no further major changes required.

6.2. General rules

Based on the implemented optimizations and their evaluation, the following general rules can be defined: The avoidance of incorrect entries and immediate feedback in the event of errors have been identified as important factors for user-friendliness. The validation of inputs and the immediate display of errors increase the accuracy and reliability of model use. Therefore, the model must clearly show which goods are produced at the respective stations. Users need clear information about which goods are produced at which stations in order to understand the production processes and make decisions. This helps to avoid misunderstandings and increase the effectiveness of use, by making the material flow and the type of transport clear.

The following rules for the user interface could also be established based on the requirements and the evaluated changes in the model: The user interface must be designed intuitively and be operable without additional instructions to minimize the learning curve and increase efficiency. Additionally, the user interface must clearly show which parameters have been set to understand and control the effects of their settings. The validation of inputs and the immediate display of errors increase the accuracy and reliability of model use. The user interface must prevent and highlight the entry of invalid values. Also, protection mechanisms against incorrect entries and unwanted formatting changes are essential to ensure model consistency and reliability. Our evaluation confirmed that a well-structured main menu contributes to efficiency by simplifying navigation and facilitating access to essential functions. Therefore, the user interface must display relevant overviews in the main menu. Furthermore, the separation of user interface and model development protects against unwanted changes and increases the stability of the system.

7. Summary and outlook

This study aimed to enhance the usability of simulation models through a comprehensive approach developed in collaboration with an industrial partner. Although, existing literature provided foundational insights to improving user-friendliness in model visualization, and results presentation, a cohesive implementation guideline was lacking. Therefore, an existing simulation model was revised with a focus on accessibility for novice users, guided by personas and scenario-based evaluations. With the eye-tracking study, experts can analyze where users spend too much time looking and add, remove, or highlight elements accordingly. We found that overly detailed information overwhelms users and does not contribute to decision-making. Additionally, not every type of user needs full control over all aspects of the model, as this leads to complexity and error-proneness. Limited operability can even increase user-friendliness by focusing on essential and relevant functions.

However, the model requirements were primarily validated by focusing on a single use-case. Consequently, testing and evaluation involved a small user group. Additionally, the choice of interface was restricted by available software provided by the industrial partner, potentially limiting broader applicability. While Excel served well for prototyping, future iterations should consider a wider range of simulation software to solidify the concept's universality.

The conceptual framework offers a strong foundation for future research directions, including validating error handling for additional simulation parameters or enhancing user-friendly visualization of simulation outcomes. Nevertheless, broader testing beyond a single use-case is essential to verify the general applicability and long-term effectiveness.

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