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# A TOOL-BASED APPROACH TO ASSESS SIMULATION WORTHINESS AND SPECIFY SPONSOR NEEDS FOR SMEs

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## ABSTRACT

Many small and medium-sized enterprises (SMEs) still refrain from using discrete-event simulation (DES) to plan, implement and operate their manufacturing systems. Given the increasing relevance of DES - e.g., as the basis for digital twins - a need for action is therefore identified. While the reasons for the seeming aversion to DES in the context of SMEs are well-researched, the following work's main objective is to present a tool-based approach that aims at supporting SMEs overcome the hurdles of the early stages within a structured simulation study. This is done through the assistance of users in identifying issues that are simulation-worthy as well as approaching the possible tendering and development of accurate problem specifications. Furthermore, the research methodology and the results of the commenced Delphi study are outlined. A critical reflection and an outlook on the topic are provided as well.

## 1 INTRODUCTION

The latest report of the World Trade Organization highlights the paramount importance of small and medium-sized enterprises (SMEs) in the context of the world economy, which has had a hard time recovering from recent crises (World Trade Organization 2021). Therefore, SMEs have to find the means to apply suitable tools for running their business operations in an environment that is becoming increasingly disruptive, especially in the context of planning, implementing and operating production and logistics systems. Discrete-event simulation (DES) is a proven method for solving problems related to production systems, which exhibit dynamic behavior, stochastic properties (Gutenschwager et al. 2017), and increasing complexity (Lichtenstern et al. 2021; Martin et al. 2021). A strong case can be made for the increasing relevance of DES as an essential enabler for digital twins (Shao et al. 2019), another field where SMEs may face more significant challenges compared to their corporate competitors, of production and logistics (Jain et al. 2019), and other data-driven methods, such as Machine Learning (Greasley 2020). Typically, the barriers to applying DES in SMEs can be attributed to limited personal and financial resources or expertise (Yu and Zheng 2021). Even though relevant research efforts in simulation education can be identified (e.g., Kudlay et al. 2020; Lawson and Leemis 2021), immediate operational support is still lacking for users of DES in SMEs. Existing DES-support tools outside the sole scope of simulation education are typically generic (i.e., they do not differentiate between SMEs and larger enterprises), or they support specific aspects of a simulation study such as data acquisition and visualization (Bogon et al. 2012; Byrne et al. 2014; Byrne et al. 2015; Lattner et al. 2011). The solution presented in this paper falls into the latter class of tools.

However, while there may not yet be a holistic SME-tailored solution, the results of this work shall provide a starting point centered around the SME user of DES and the early stages of a simulation study. Those early stages, which are the main focus of this paper, are the identification of DES-worthy problems and the specification of sponsor needs.

Typically, the execution of a simulation study in production and logistics is described through different procedure models (Banks et al. 2010; Law 2019; Pitsch et al. 2009; Rabe et al. 2008; Rossetti 2015), which share many commonalities despite a few structural differences. Due to the nature of formalization of the procedure models (i.e., they are start-to-end processes), early stages can be identified (i.e., the above-mentioned identification of DES-worthy problems and the proper specification of sponsor needs).

Starting even before the specification of sponsor needs, it is of great importance for SMEs to discuss a problem's DES-worthiness. While big companies may have an established playbook or even a department responsible for DES, that is often not the case in SMEs, and practical knowledge about DES is scarce. Those circumstances are addressed in this work by first identifying DES-worthy problems during the life cycle of production and logistics systems. The identification is based on a literature review, which is subsequently used to compile a checklist of exemplary problems. Following the compilation, a Delphi study is conducted to ensure the credibility and relevance of the checklist. Based on the latter, a prototype tool is developed to provide operational support.

The following chapters explain the research methodology and procedure (chapter 2), their generated results (chapter 3), and the development and evaluation of the support tool (chapter 4). Lastly, chapter 5 summarizes all relevant findings, critically reflects upon them, and presents an outlook on further research needs and activities.

## 2 RESEARCH METHODOLOGY

The applied research methodology includes several interrelated activities, shown in Figure 1. First, DES fields of application in the planning, realization, and operation of production and logistics systems are identified and classified. The identification is made through a literature review (see 2.1) focused on case studies in which DES is used to solve problems in the specified domain. The classification follows the systematics of VDI (standard) 3633 (VDI 2014), which standardizes DES-application in production and logistics ("VDI" is the abbreviation for "The Association of German Engineers").

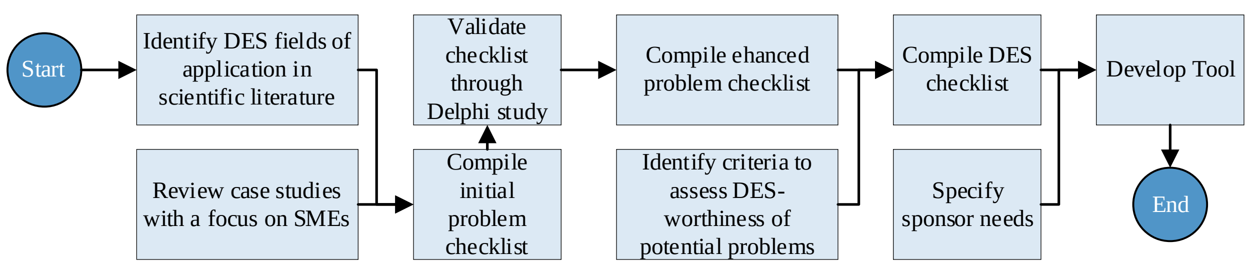


Figure 1: Activity structure of the presented work.

### 2.1 Literature Review

A systematic literature review is conducted to identify relevant DES-application fields in production and logistics and related case studies focusing on SMEs. Jesson et al. (2011) and Fink (2020) explain procedural methodologies, adopted here with slight changes, for a fully systematic review. The first step is defining the research question as a starting point for further activities (Jesson et al. 2011) and the research question in this work is: *Which problems of SMEs in production and logistics systems can be solved using DES?* Next, the search is conducted using the search strings *(discrete event* AND simulation) AND (small and medium enterprise*) AND (logistic*OR manufacturing* OR production*)*, in utilizing eight different databases (Web of Science Core Collection, ACM Digital Library, IEEE Xplore, Business Source Premier, WISO, Google Scholar, ScienceDirect and Emerald Insight). Further, an additional, logically equivalent search in German is performed. To reduce the initial number of found publications (4,754 pieces of literature), sampling is applied (for further details see Fink (2020)) and the first 50 publications of each database are analyzed. All publications in which the authors use DES to solve a particular problem in production or logistics systems of SMEs are considered relevant. The literature review returns 29 case studies from 1999 to 2019, which originate in civil and industrial engineering, the automotive industry, and the metal processing sector. This sector-related distribution of DES-application is confirmed in the scientific literature (e.g., Dispan and Schwarz-Kocher 2018; Gutenschwager et al. 2017; McGinnis and Rose 2017). Based on the system life cycle classification (i.e., planning, implementation, and operation of a system (VDI 2014)), a list of relevant case studies is compiled and later analyzed (see Table 1). The outcome is an initial problem list containing common problems solved via DES in SMEs.

## 2.2 Delphi Study

To reduce bias and ensure completeness, an evaluation of the initial problem list is conducted. Therefore, an expert-based evaluation via a Delphi study is conceptualized due to its flexibility in terms of location and time, thus tending to increase participation rates. Another advantage is anonymous feedback (Häder 2014) (i.e., making participants open up about internal problems without tarnishing their company's situation yet gaining valuable insights into other companies). The multiple rounds of the Delphi study, while time-consuming, ensure that participants reflect on the results and thus provide additional input to the developed problem checklist (Häder 2014). The general structure of the conducted survey can be seen in Figure 2. Regarding the acceptance, if a criterion does not change from one round to the other, it may be considered stable. A stable criterion does not necessarily conclude consensus; thus, consensus status is checked and granted when 75 % of the participants agree. For more details like the practical realization of the Delphi study via lime survey or the consensus calculation, we refer to Amaral-Bicalho (2021).

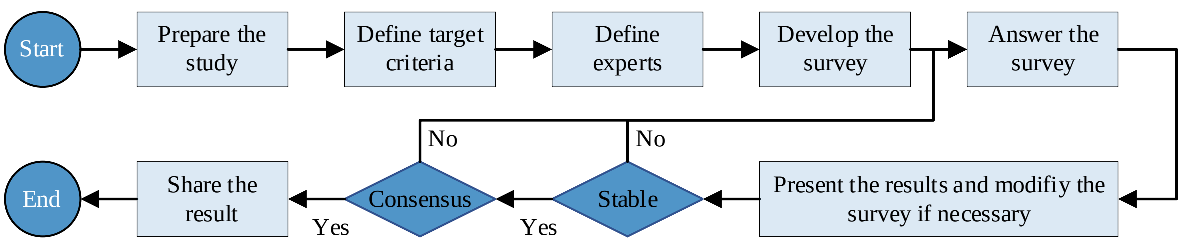


Figure 2: Structure of the Delphi study.

# 3 RESULTS OF THE LITERATURE REVIEW AND EVALUATION

This chapter explains the results of the conducted literature review assembled into a list of DES-relevant problems (3.1). Further covered are the results of the checklist validation through the Delphi study (3.2) and the identification of criteria for DES-worthiness from the scientific literature (3.3).

## 3.1 DES Fields of Application in Production and Logistics

The application goals of DES are generally aligned with typical production and logistics goals, such as minimization of lead time, schedule variance, utilization, and inventory management (Wenzel et al. 2018). Other problems are comparing solutions for sound decision-making, improving a (production) system by selecting the most suitable solution, improving the understanding of the system, verifying different theories, ensuring the (factory) planning, and predicting system behavior (Rossetti 2015; Wenzel et al. 2018).
Using the classification featured in VDI 3633 (VDI 2014), the following Table 1 of SME-specific case studies is organized by an ID number, the corresponding author(s), a problem description, and the life cycle phase of the system (Planning (P) and Operation (O)) where DES is applied.

Table 1: Overview of the relevant case studies.

| # | Author (year) | Problem description |
|---|---|---|
| 1 | Park et al. (1999) | Decision-making on the tactical management of photomasks (P) |
| 2 | Dewhurst et al. (2001) | Design of a new product line and production process; introduction of a new range of chucks (P) |
| | | Explore failures of lathes (turning machines) (O) |
| 3 | Dietel and Hanisch (2001) | Decision on the type and assortment of kilns (order sequence) (O) |
| 4 | Thormann et al. (2001) | Improvement of material flow via automation (P) |
| 5 | Dietel and Bennemann (2001) | Decision on the sequence formation of casting orders (P) |
| 6 | Koebernik et al. (2001) | Design of a new production strategy due to high inventories of semi-finished and finished products and overworked employees (P) |
| 7 | Tatsiopoulos et al. (2002) | Evaluation and justification of the implementation of an E-Commerce system solution (P) |
| | | Analysis of possible scenarios for dealing with an unexpected increase in demand (O) |
| 8 | O'Kane (2004) | Decision-making regarding the purchase of a machine (P) |
| 9 | Byrne and Heavey (2006) | Decision-making on whether to share information between supply chain partners (P) |
| 10 | Thron et al. (2006) | Decision-making on participation in a retailer's supply data system (P) |
| 11 | O'Kane et al. (2007) | Analyze the impact of decisions regarding system performance (machine purchases, scheduling alternatives, and process flow changes) (P) |
| 12 | Spieckermann (2008) | Factory planning (P) |
| 13 | Aguirre et al. (2008) | Improving the capacity of production due to high demand (P) |
| 14 | Hvolby et al. (2012) | Decisions regarding future production strategies (P) |
| 15 | Ehrenberg and Zimmermann (2012) | Determination of scheduling for a make-to-order production (P) |
| | | Difference between planned and realized scheduling (O) |
| 16 | Pereira et al. (2012) | Improvement of a production process with a highly variable environment (P) |
| 17 | Dombrowski and Ernst (2013) | Design and evaluation of optimized factory layout variants (P) |
| 18 | Zupan and Herakovic (2015) | Analysis based on different scenarios to balance production lines (P) |
| 19 | Aggogeri et al. (2015) | Decision-making in manufacturing (adding a new product; buying new machinery; changing batch size strategy; changing demand) (P) |
| 20 | Yang et al. (2016) | Deciding on production planning and control (scheduling), taking into account the influence of unforeseeable events (O) |
| 21 | Penazzi et al. (2017) | Redesign and management of a Job-Shop System (P) |
| 22 | Sobottka et al. (2017) | Planning a factory with new technology and increased capacity (P) |
| 23 | Sulistio and Hidayah (2017) | Increasing productivity to deal with dynamic demand (P) |
| 24 | Richter et al. (2017) | Decision-making about the production sequence and staff assignment (O) |
| 25 | Faisal (2018) | Value stream mapping within the implementation of lean manufacturing (P) |
| 26 | Stoldt et al. (2018) | Evaluating the effects of planned changes to tools before they are implemented in the procurement process (P) |
| 27 | Di Leva et al. (2020) | Long- term decision-making of the disposition model (P) |
| | | Short-term decision-making of the disposition model (O) |
| 28 | Yang et al. (2019) | Design and planning of a pull system using a Multi Constant Work In Process (CONWIP) system. (P) |
| 29 | Grube et al. (2019) | Factory planning (layout of the new plant) (P) |

Based on the analysis of the identified case studies and further relevant pieces of simulation literature, a series of generic problems - that justify the use of DES - are being formulated. Figure 3 structures these problems according to the system life cycle phases found in VDI 3633 (VDI 2014).

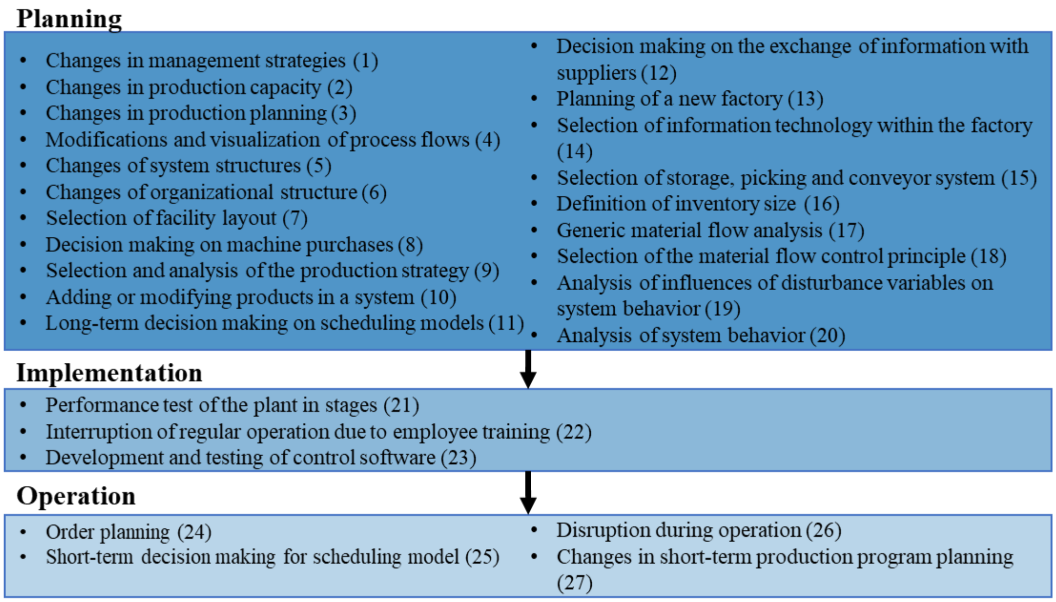


Figure 3: DES-worthy problems in the life cycle phases of technical systems.

The majority of the case studies (labeled from 1 to 29) address problems in the planning phase, which confirms the findings of other authors such as Gutenschwager et al. (2017) and Negahban and Smith (2014). In the planning context DES is primarily applied to analyze and improve system and process designs (VDI 2014). The most prominent planning problems identified in the literature review are layout planning (12, 17, 21, 29) and decision-making on the number of needed machines (i.e., performance analysis) in a system (8, 11, 19). Since whether or not to exchange information with (critical) suppliers can strongly impact SMEs' performance (Ihlau and Duscha 2019), different scenarios and performance indicators (e.g., lead-times with or without information sharing) can be simulatively analyzed using DES (9, 10). Furthermore, DES assists in the modification and visualization of existing structures and helps SMEs understand the effect on a system's performance (11, 26) or their value streams (25).

The literature review identifies a lack of case studies in SMEs during the implementation phase (for generic examples see Gutenschwager et al. (2017) or VDI (2014)). The operation phase is characterized by an immediate decision horizon (VDI 2014). Here, sequencing and resource allocation problems (3, 24) for a short time period as well as decision-making during machine failures (2, 15) are identified as DES-worthy problems. In these situations, using what-if analysis through DES can help solve these problems (7, 15).

### 3.2 Results of the Delphi Study

The Delphi study went on for three rounds with a processing period of two weeks per round and a response rate of 93 % for the first, 73 % for the second, and 47 % for the last round. Due to the design of a Delphi study - being a lengthy round-based process (described in 2.2) - a decline in the number of participants is to be expected. The questionnaire consists of four parts, with the first one being a general survey and the following parts covering the planning, realization, and operation phases, respectively. The general questions assess whether the participating companies are SMEs according to the categorization of the EU Commission (EU Commission 2003) and if they already apply DES in production or logistics. In the following three parts, the participants rate the importance (i.e., the relevance of applying DES to the specified problem instead of another potential problem solving method) and frequency of each identified problem on the list. Each identified problem's frequency is rated on a scale ranging from "less frequently" to "daily" (seven categories in total), and each problem's importance is rated on a scale ranging from "not important" to "important" (four categories in total). Further, the completeness of the checklist is evaluated. A commentary field allows each participant to leave a comment regarding existing problems or to request the addition of a problem. After the first round, the feedback from multiple participants made a few changes in the questionnaire necessary, adding the following problems: "Change of production system requirements due to new products (28)", "Personnel planning (29)", "Unclear or changing management objectives (30)", and "Decision-making on proper production processes (31)". Additionally, an option for "no application" is added to each stated problem within the survey to identify problems where DES - according to the experts - is generally not applied. Furthermore, some problems are reworded to clarify their meaning, thus avoiding misinterpretations (e.g., "Selection of layout" is changed to "Selection of production layout") and their relation to the life cycle phases is removed. Additional questions are added, asking the participants whether or not the list is complete to achieve consensus. The second round analysis leaves five problems with an unstable outcome for their frequency and one problem with no consensus regarding its importance. Also, the newly added problems (28-31) are only included once and thus need further investigation. Only those problems are taken to a shortened third round to reduce the time required to take part in the round and therefore keep the participation rate high. After the third round, all problems except one are considered stable, and the experts have reached a consensus. Therefore and because of the declining participation rates, no fourth round is conducted, and the Delphi study is terminated. Most of the participating companies (79 %) do not use DES. The participating SMEs that use DES notice improvements in their production and logistics systems and processes. These results confirm the findings in the existing simulation literature and underline the need to support SMEs in preparing and conducting simulation studies. The list of possible problems is considered complete by 91 % of the participants. An additional suggestion from one of the experts is to incorporate examples for the given problems since some are too abstract or hard to grasp. This advice is carried over to the development of the tool prototype (see 4), allowing for a better user experience.

The following Figure 4 summarizes how the participants evaluated the importance and frequency of the problems that are shown in Figure 3. It is concluded that no problems are considered to be unimportant (quadrants III and IV). Infrequent problems (quadrant I) tend to be slightly less important than more frequent ones (quadrant II). The computed mean importance of the shown problems is "3.3" in quadrant I and "3.6" in quadrant II.; however, those insights are not statistically significant. The evaluated list represents DES-worthy problems based on the conducted Delphi study.

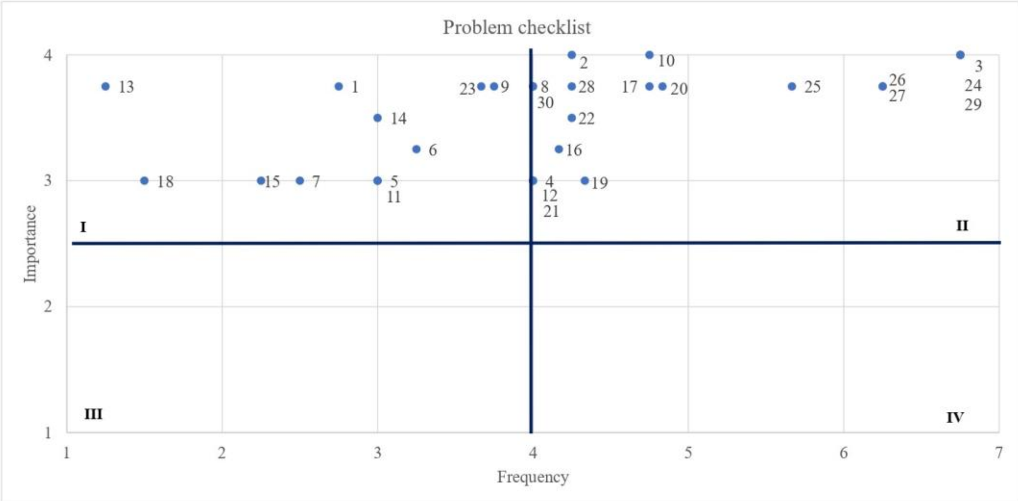


Figure 4: Frequency and importance of SME-specific problems.

### 3.3 Criteria for DES-Worthiness

An essential prerequisite for conducting a simulation study is to determine whether or not a problem can be appropriately solved by DES, i.e., if it is DES-worthy (for a more detailed elaboration see Wenzel et al. (2008)). Therefore, criteria for DES-worthiness are identified in the pertinent simulation literature (Banks 1998; Law 2015; März et al. 2011; Robinson 2004; Rossetti 2015; VDI 2014; Wenzel et al. 2008). The following Table 2 contains different criteria regarding DES-worthiness as described by other authors. The importance of the identified criteria is assessed via pairwise comparison, where each criteria pair is compared on a predefined scale (Binner 2016; Drews and Hillebrand 2007). This is done to evaluate the importance of each criterion by comparing the number of times that it is mentioned in the scientific literature. Table 2 summarizes the results of the pairwise comparison. From row to column, if one criterion is cited more often than the other, it is considered more important (equals 3); if less often, it is considered less important (equals 1), and if both are cited equally often, they are considered equally important (equals 2). Next to the comparison, the sum of the points for each criterion and a relative criterion weight are calculated. The weighted criteria are used to formulate decision rules about DES-worthiness in the software prototype, developed to support SME users.

Table 2: Pairwise comparison between the criteria for DES-worthiness.

| **Criterion** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | ∑ | **Weight** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** Stochastic influences (dynamic system) | - | 3 | 3 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 25 | 14 % |
| **2** Visualization and communication (transparency) | 1 | - | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9 | 5 % |
| **3** Performance estimation of dynamic systems | 1 | 3 | - | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 13 | 7 % |
| **4** Experiments for scenario analysis | 2 | 3 | 3 | - | 2 | 3 | 3 | 3 | 3 | 3 | 25 | 14 % |
| **5** Analysis of the system over a long time period | 2 | 3 | 3 | 2 | - | 3 | 3 | 3 | 3 | 3 | 25 | 14 % |
| **6** Detailed analysis of a short period | 1 | 3 | 2 | 1 | 1 | - | 1 | 1 | 1 | 2 | 13 | 7 % |
| **7** Interconnection of elements in the system | 1 | 3 | 3 | 1 | 1 | 3 | - | 2 | 2 | 3 | 19 | 11 % |
| **8** Large number of elements in a system | 1 | 3 | 3 | 1 | 1 | 3 | 2 | - | 2 | 3 | 19 | 11 % |
| **9** The non-existence of the real system | 1 | 3 | 3 | 1 | 1 | 3 | 2 | 2 | - | 3 | 19 | 11 % |
| **10** Less restrictive assumptions for uncertain data | 1 | 3 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | - | 13 | 7 % |
| ∑ | | | | | | | | | | | 180 | 100 % |

## 4 TOOL DEVELOPMENT AND EVALUATION

Based on the results of chapter 3, the following sections describe a set of tool requirements (4.1) and the developed software prototype itself (4.2), which is evaluated in (4.3).

### 4.1 Tool Requirements

First, a series of functional and non-functional requirements are identified and formalized to develop a suitable tool (Further details on the identification of requirements can be found in Amaral-Bicalho (2021)). A requirement's obligation, desire, and intent, are formalized by including "must", "should", and "will" respectively (Queins and Rupp 2021). Table 3 (see 4.3) lists all tool requirements. The requirements specify functional (1-11) and non-functional (12-19) tool aspects. The latter are derived from SME-specific characteristics (12-14), security requirements (15) (Byrne and Heavey 2006), as well as usability (Sommer and Plankenhorn 2004) and interoperability considerations (16-19).

### 4.2 Tool Prototype

The developed prototype is an MS-Excel application and VBA scripts (Visual Basic for Applications) implement additional functions. The logic of the prototype is shown in Figure 5. The user starts on a landing page and can visit different functional areas via buttons. Each active area in the tool is described using a unique color scheme and is located on its respective excel sheet. The tool guides the user through its areas based on their inputs, initiating various processes and subprocesses. Further informational documentation assists the understanding of the tool or the process and ensures the tool works as a stand-alone solution. Each sheet contains an introduction and either returns the user to the landing page or ends the routine. Further details regarding the tool can be found in Amaral-Bicalho (2021).

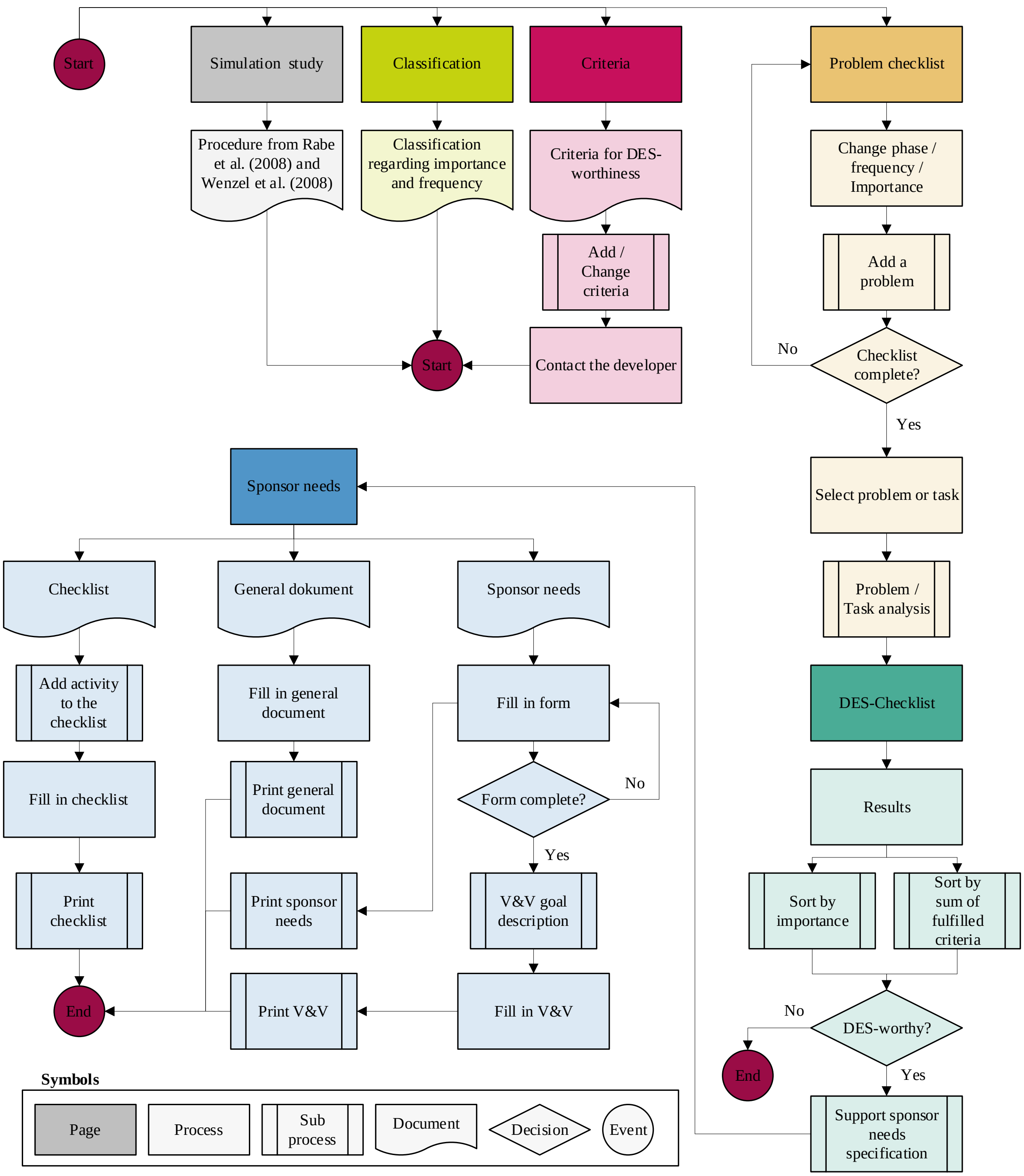


Figure 5: Prototype program sequence.

### 4.3 Evaluation of the Tool

The evaluation consists of a checklist for developers and a survey for potential users and thus provides feedback from technical and user-centric points of view. The evaluation criteria are based on the previously defined catalog of requirements in Table 3 as well as criteria for assessing the appropriateness for the task, conformity to expectations, controllability of the tool, and robustness against application errors (International Organization for Standardization 2002). The tool completely satisfies most of the criteria (82 %), and the rest of the criteria is seen as partially fulfilled due to software or user requirements (e.g., pricing, data security, handling of user errors). A more detailed description of the procedure model for a simulation study is desired. Overall, however, the evaluation confirms the tool's usability for SME users.

Table 3: Tool requirements for the software prototype.

| ID | Description | Type |
|---|---|---|
| 1 | The tool **must** have a list of problems. | Functional |
| 2 | The tool **must** allow the selection of a problem and a further description. | |
| 3 | The tool **must** contain a list of DES-worthy criteria. | |
| 4 | The tool **should** update the database. | |
| 5 | The tool **must** demonstrate the DES-worthiness of the task. | |
| 6 | The tool **must** link the task to the DES-worthiness criteria. | |
| 7 | The tool **must** link the task with the support section of the target description. | |
| 8 | The tool **must** guide the user to the creation of the target description document. | |
| 9 | The tool **must** allow filling in the document of the target description. | |
| 10 | The tool **should** allow printing the document from the target description. | |
| 11 | The changeability of criteria for determining the DES-worthiness **must** be restricted. | |
| 12 | The tool **must** be cost-effective. | Non-functional |
| 13 | A manual explaining the tool **must** be available. | |
| 14 | The tool **should** explain the procedure of a simulation study. | |
| 15 | The tool **must** provide data security | |
| 16 | The tool **must** be user friendly. | |
| 17 | The tool **must** require little training. | |
| 18 | The tool **should** be flexible to adapt to different industries. | |
| 19 | The tool **will** communicate with other software. | |

## 5 SUMMARY AND OUTLOOK

This paper describes an initial approach to overcoming the circumstance that SMEs are reluctant to use DES in production and logistics despite its increasing importance. Lack of resources and lack of know-how are identified as leading causes for this situation in the scientific literature. Based on those characteristics, a software tool is developed to enable SMEs to independently identify problems worthy of DES and specify their sponsor needs. In order to achieve the outlined result, a checklist for the identification of DES-worthy problems is compiled with the help of relevant scientific literature and the consideration of pertinent case studies (in total, 29 relevant case studies in the context of SMEs are identified and analyzed). The checklist is then evaluated and enhanced via a Delphi study. Complementing this checklist, general criteria of DES-worthiness are identified from the literature, weighted to assess their relevance, and merged with the previously identified DES application fields in a final DES checklist. The checklist represents the starting point for the development of the software tool, which is developed taking into account functional as well as non-functional requirements and is assessed in the course of an expert evaluation. The tool's suitability is confirmed for the desired outcome formulated at the outset, but further research needs can be identified. The relevance of the general criteria of DES-worthiness was determined by a quantitative weighting (based on a pairwise comparison that compared the problem frequency in the scientific literature). An expert evaluation on the relevance of the criteria is pending and will be pursued as part of further research efforts so that the results obtained can be assessed to improve the tool's decision-making regarding DES-worthiness. Furthermore, the aim is to evaluate the developed tool in a more comprehensive user group from the SME sector so that industry-specific application aspects, in particular, can be identified and better taken into account. The presented work focuses on the earliest phases of a simulation study from the perspective of SMEs. To develop a holistic solution for the target group mentioned, the subsequent phases of a simulation study must also be investigated. A suitable extension of the tool must address the resulting requirements for user support. This extension represents the core of research efforts that follow from this.

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