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Notations in Simulation Development: A state-of-the-art Literature Research

Notationen in der Simulationsentwicklung: Eine state-of-the-art Literaturrecherche

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Abstract: With this systematic literature review we investigate the use of graphical tools and standard notations, such as the Business Process Modelling Notation (BPMN) and the Unified Modelling Language (UML), in the development of simulations. In our review, we focus on different simulation methods, such as agent-based simulation, discrete event simulation, system dynamic simulation and hybrid simulation approaches. We examine more than 1.000 scientific articles, which cover simulation approaches in the area of operations management and business. Our results provide insights into the frequency of the use of notations in simulation development, the relationship between notations and simulation methods and secondarily the frequency of used simulation methods in the business environment.

1 Problem Statement

In recent decades, the complexity of corporate decision-making for executives as well as managers has increased significantly. In addition to accretive requirements for information systems (IS), increasingly intertwined business processes, and intricate business relationships, the implications of modern trends such as the Internet of Things and Industry 4.0 have led to unprecedented complexities in corporate decision making (Xu et al. 2016). As a result, companies and decision-makers face significant challenges when designing or adapting business processes or operational systems (Auf der Landwehr et al., 2020). Computer simulation methodologies represent one possibility for decision support and evaluation in the managerial environment since they have proven to be an effective tool for description, exploration, and theory development (Davis et al. 2007; Auf der Landwehr et al. 2020). Dynamic simulation can be described as a “method for using computer software to model the operation of ‘real-world’ processes, systems, or events” (Davis et al. 2007, p.481). The burgeoning need for support, higher availability of computer resources, and the improved applicability and suitability of simulation environments could explain the increased number of simulation projects, publications, and combinations of simulation methods in recent years (Xu et al. 2016; Brailsford et al. 2019). Here, the increased complexity of real-world problems, lead to a need for greater coordination and a higher intricacy in developing simulations. The information interface between the business perspective and the technological development of the conceptual model as an abstraction of the real world and the transition between theory development as well as simulation modelling is perhaps one of the most important aspects of simulation development and often the key challenge in the communication between functional experts and developers (Davis et al. 2007; Robinson 2013; García et al. 2014; Wagner 2018; Brailsford et al. 2019).

This type of interface challenge has been widely researched, and there are many studies available in the literature on IS and software engineering. Regarding the field of classic software development, standard notations for conceptual modelling are widespread and used extensively. However, in simulation development, such notations are not yet been formally established (Wagner 2018; Wilsdorf et al. 2020). Nevertheless, standard notations seem to be highly useful in simulation-related research and application contexts (Rosenthal et al. 2018).

The research gap concerning the use of notations in simulation was identified by Rosenthal et al. (2018), who conducted a literature analysis to investigate the usefulness of notations in simulation development. While their work provides a reasonable overview, their contribution is limited to business processes and does not consider different simulation methods. Jahangirian et al. (2010) and Brailsford et al. (2019) did consider different simulation methods, but did not address notations.

To acquire a holistic and up-to-date view of currently used simulation methods and potentially used notations and graphical tools, it is important to discover which notations are used and the extent to which they are used in various disciplines of the simulation community. In a first unstructured review of current literature considering 183 simulation approaches, we noted that there are publications that use standardized notations in their simulation approach, but the spread of standard notations in simulations has not been explored (Jahangirian et al. 2010; Rosenthal et al. 2018; Brailsford et al. 2019). To rectify this, we undertake a *systematic literature review* that analyzes the prevalence and utilization of notations in simulations. We thus propose the following research questions.

RQ1: How many scientific articles use standard notations or graphical tools for simulation development in the business domain?

RQ2: For which simulation methods are notations used and how often?

Based on the subject's topicality, the previous analysis of Rosenthal et al. (2018), and to focus our research framework on current events as well as changes, we propose a review period from 2015 to 2020. We thus rely on the findings of Rosenthal et al. (2018), although they addressed a different research focus. A five-year scope is also useful to set a limit for the literature search, in order to allow for a widespread conceptual assessment level (i.e. different simulation methods and business applications). Due to the relevance of simulation-based approaches for the field of production and logistics (P&L), we specifically focus on research approaches in this particular business area. Nevertheless, to ensure a comprehensive overview, we also take into account more general *business applications* (i.e. Business and workflow).

2 Theoretical Background

We focus on simulation applications from the business domain, using the 26 *business applications* proposed by Shafer and Smunt (2004), Brailsford et al. (2019), and the "Applications of simulation techniques in manufacturing and business" (Jahangirian et al. 2010, p.5-7). From this *business applications*, we derived six clusters to group the articles for our analysis, as per Jahangirian et al. (2010) (to be seen in Table 1).

Table 1: Business simulation applications (26); Business simulation clusters (6) [Jahangirian et al. 2010 **(a)**; Shafer & Smunt 2004 **(b)**; Brailsford et al. 2019 **(c)**]

Production and manufacturing	**Logistic & Supply Chain Management**
Manufacturing **(c)** & Purchasing **(a, b)**	Distribution **(b)** & Just-in-time **(a, b)**
Cellular manufacturing **(a, b)**	Inventory management **(a, b)**
Production planning & inventory **(a, b)**	Supply chain management **(a, b, c)**
Workforce planning **(a, b)**	Transportation management **(a, c)**
Business and workflow	**Management**
Assembly line balancing **(a, b)**	Financial management **(a)**
Capacity planning **(a, b)**	Maintenance management **(a)**
Facility location **(a, b)**	Knowledge management **(a)**
Forecasting **(a, b)**	Organizational design **(a)**
Resource allocation **(a, b)**	Project management **(a, c)**
Scheduling **(a, b)**	Quality management **(a)** & Strategy **(a, b)**
Training	**Process**
Management training & education **(a)**	Process engineer-manufacturing **(a, b)**
	Process engineer-service **(a, b)**

The following list provides an overview of the simulation methods used in the area of *business applications*. The methods that cannot be assigned to the presented methods, e.g. traffic simulation, are termed as other simulation (**OS**) (Jahangirian et al. (2010).

System Dynamics (SD) is a time-continuous method characterized by positive and negative feedback loops. SD aims to create a macroscopic image of systems focused on the whole system rather than short-term events (Morgan et al. 2017).

Discrete Event Simulation (DES) is mostly used on the micro- and mesoscopic level to model events in time-discrete systems. Entities pass through a series of events so that the flow, variability, and random factors in a system can be observed. DES does not aim to obtain feedback from the system (Morgan et al. 2017).

Agent-Based Simulation (ABS) systems consist of a network with agents that follow predefined rules and conditions in a time-continuous system. The agents then interact with each other and the environment, allowing inferences to be made about the system or individual agents (Macal 2016; Brailsford et al. 2019).

Monte Carlo Simulation (MC) is one of the oldest simulation methods, especially in the *fields* of production or processes. MC solves static or numerical problems, such as evaluations or risk deviations (Jahangirian et al. 2010).

Hybrid simulation (HS) is a combination of two or more simulation methods that are combined to solve problems simultaneously (Mustafee et al. 2018). HS can represent both time-continuous and time-discrete systems (Jacob et al. 2010). Modern HSs can be developed in a single development environment and are mostly meshed internally without external interfaces (Brailsford et al. 2019).

In addition to many conceptual models for the development of simulations from the simulation community - see the overview by Wilsdorf et al. (2020) - there are notations in other areas of computer science that have long been accepted as standard (Rosenthal et al. 2018; Wilsdorf et al. 2020). These notations from software development are also used in the development of simulation models. The best-known current notations for development or business process modelling are:

Business Process Modelling Notation (BPMN) is a widely used notation and official standard for process modelling. All information about BPMN can be found on the official OMG site (OMG 2010). Due to its widespread use, there are many approaches and attempts to use BPMN for simulation, especially in the area of DES (Rosenthal et al. 2018). To use BPMN for modelling and describing simulation projects, many authors have suggested extending BPMN notation by adding input, output, and other environmental parameters. A further step is the use of extensions that transform BPMN into an execuTable program, such as eBPMN, domain-specific simulation languages that softens the boundaries between notation and simulation. Thus, for example, eBPMN can be considered as DES which are implemented with the help of graphic notations (Bocciarelli et al. 2019).

Unified Modelling Language (UML) is an internationally standardized software modelling language and is likely the most widely used modelling technique in software engineering, especially in object-oriented development (Xie 2008). All information about UML can be found on the official OMG (OMG 2017). Beyond software development, UML is also used in business process modelling due to the large number of possible modelling tools provided (Allweyer 2016). UML can be used for simulation development (i.e., UML activity diagrams), but there are also attempts to modify UML for simulation-compliant notations (i.e., Systems Modelling Language, SysML) (Weyprecht & Rose 2011; Rosenthal et al. 2018).

Stock and Flow Diagrams and **Causal Loop Diagrams** (hereafter together **Stock&Flow**) do not represent a IS notation per se; rather, the diagram types are used to represent dynamic systems. With Stock&Flow, system relationships can be represented in a continuous space with feedback loops (Bala et al. 2016).

We have included the graphical formalization of the Stock&Flow, for the purpose of completeness, as this is frequently used in SD. There are also other notations that can help to plan and develop simulation projects, such as PetiNets, or (extended) event-driven process chain, which we abbreviate collectively as **EPC**.

3 Methodology

Our procedure chosen can be seen in Figure 1. The ***first step*** was "scope definition," or the definition of the problem and formulation of the research questions. For this step, we - the authors - used an unstructured literature review that we performed together in a 1-day workshop. In the ***second step***, we elaborated the methodology, the related, theoretical foundations, and the most important terms of our project. This theoretical foundation is found in the previous *Chapter 2* and starts with a definition of *business applications* for simulation projects and publications (Jahangirian et al. 2010; Brailsford et al. 2019). In addition, we discuss notations for simulation development (Robinson 2013; Rosenthal et al. 2018). There is a special focus on the BPMN and UML. But *Stock&Flow* and other notations (e.g. EPC) are also under consideration (Allweyer 2016; Rosenthal et al. 2018; Robinson 2020). Furthermore, various simulation methods are described, including *SD, DES, MC,* and *ABS*. *HS* and *OS* are also discussed (Jacob et al. 2010; Brailsford et al. 2019).

After laying out the theoretical foundation, we begin the systematic literature review in *Chapter 4*, which is divided into a database search (***step three***) and deep search (***step four***) following the two-step model of Jahangirian et al. (2010). The database search included journal and conference selection, a literature database definition, and the main database search, which included a continuous evaluation of sources and exclusion of irrelevant publications through the allocation of business and simulation applications as well as reduction of duplicate or non-English publications. (Vom Brocke et al. 2009). Our abstract filtering included title review, abstract review, a keyword review of the full text, and a consideration of the full research approach to classify the simulation method and the use of notations. Through the deep search, we summarized the literature search process of Vom Brocke et al. (2009), which suggested an additional backward and a forward search of the most relevant articles for quality assurance. For the ***fifth step*** of the literature analysis, we deductively developed a matrix that summarizes relevant information like the simulation method, the notation used, or the associated business application. The analysis of the findings merged in the matrix, are presented in the discussion in *Chapter 5*. We then summarize our results to answer the research questions in ***step 6*** (*Chapter 6*).

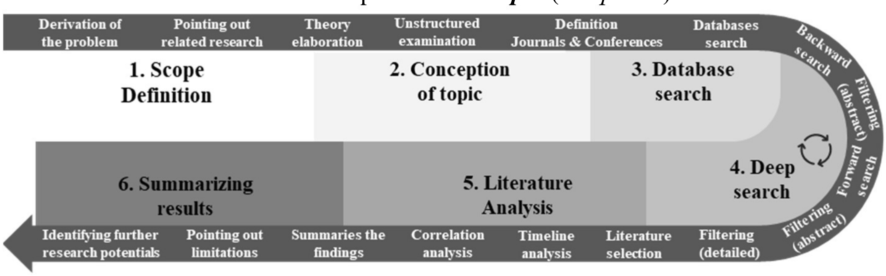

Figure 1: Procedure of our literature analysis (based on Vom Brocke et al. (2009))

4 Systematic Literature Review

As suggested by Jahangirian et al. (2010), we identified the journals and conferences relevant to our research environment to derive associated literature database for our review. To restrict the journal and conference selection, we examined the relevance in the field of simulation, impact factors of the journals, and rely on the selection of Jahangirian et al. 2010, Rosenthal et al. (2018), and Robinson (2020). In total, we focused on 12 of the most popular journals and conferences in the field of simulation. Based on the journal selection, we chose the Web of Science database for the review, which includes all the primary sources listed in *Table 2*.

Like Jahangirian et al. (2010), we searched for simulation approaches in the area of the *business applications*. We searched using the Boolean keyword combination "(*simula* OR 'system dynamic**)". To narrow the large number results, we extended the search with our business clusters, complementing the search grid of Jahangirian et al. (2010) to "*logistic*", "*production*", "*manufacturing*", "*process*", "*management*", "*business*", "*workflow*", "*supply chain*", and "*training*".

Table 2: Primary journals and conferences

Business Process Management Journal	J. of Operational Research Society
Decision Sciences	Journal of Business Research
Euro. J. of Operational Research	Journal of Cleaner Production
Int. J. of Operations & Production Management	Journal of Simulation
Int. J. of Production Research	Transportation Science
International Conference on IS	Winter Simulation Conference

After applying the main keywords and the application keywords in the title, abstract and keyword search for the selected journals, we found 1,068 articles. Whereby we have only relied on English publications. We filtered the results to 383 relevant articles by initial coding of the papers, for which we manually searched the title and abstract for business simulation approaches (Jahangirian et al. 2010). In this step we have also eliminated duplicate articles through filtering and a final manual search for duplicates. In the course of our filtering process, we used backward and forward searching in 40 particularly relevant articles and identified 11 additional articles. The final 396 articles with 400 simulation approaches were examined in detail according to the simulation methods and notation used. Here, some authors used several simulation approaches, for example for validation reason. *Table 3* offers an overview of the review. A description of the identified *business applications*, notations used, and a combined consideration of methods and notations follows in *Chapter 5*.

Table 3: Databases and relevant articles (several methods are possible)

Databases	Articles	Relevant articles	Simulations per method / relevant articles					
			ABS	DES	SD	MC	HS	OS
Web of Science	1068	385	43	111	62	9	90	73
Back&Forward	40	11	1	9	0	0	0	2
Total	**1108**	**396**	**44**	**120**	**62**	**9**	**90**	**75**

5 Analysis of the Findings

In the course of our literature analysis, we examined 396 scientific articles presenting 400 simulation approaches and have found 83 articles with notations. We subjected the applications, methods, and notations to perform a correlation analysis. For this purpose, we used the Pearson correlation coefficient (r) with 2-sided significance (p).

Between the *business applications* and the simulation methods as well as notations, only one weak correlation could be found, namely between the applications and ABS ($r = -0.122 \mid p < 0.05$). Closer inspection shows that many ABSs are assigned to "business and workflow" (34%) and P&L (39%); whereby 40% of all articles belong to P&L. *Fig 2* shows the distribution of the simulation methods used. The most commonly applied method is DES (30%), followed by HS (23%). In P&L the most used method remains DES (29%) followed by HS (26%). The use of HS increased in the five years considered. It should be emphasized that 28% of the articles from the logistics sector used HS, representing the highest usage of HS. Since HS is a combination of several simulation methods, we break down the HS types in *Fig 4*.

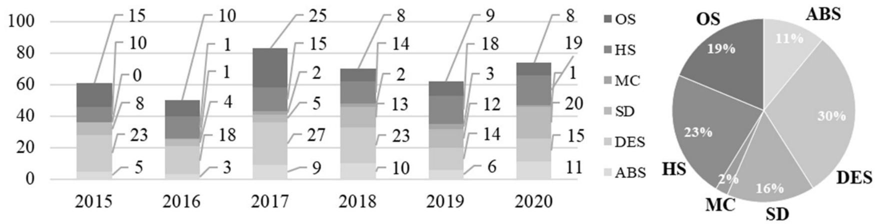

Figure 2: Methods used (400 simulations); proportions of methods (400 simulations)

The most used tool out of the 83 identified notation articles, was Stock&Flow (67%), followed by UML (17%) and BPMN (12%). The preference for Stock&Flow can be explained by the complementary attributes of Stock&Flow and SD. As seen in *Fig 3*, notations were used in 83 of the 396 articles examined, or 20.96%. In detail, the following notation uses were identified: 14 UML (3.54%), 10 BPMN (2.53%), 3 EPC (0.76%) and 56 Stock&Flow (14.14%). In addition to the reviewed notations, we found 220 articles that used flowcharts or similar schematic representations and no other notation, representing 56% of our relevant articles. Looking at P&L alone, UML was used in 3%, BPMN in 3%, EPC in 1%, and Stock&Flow in 9% of 160 P&L articles. Excluding articles that used SD or Stock&Flow, the share of notations (UML, BPMN, and EPC) is 8.5% (out of 319 articles). While an increase of the Stock&Flow can be seen, the use of UML and BPMN is constant over the studied period.

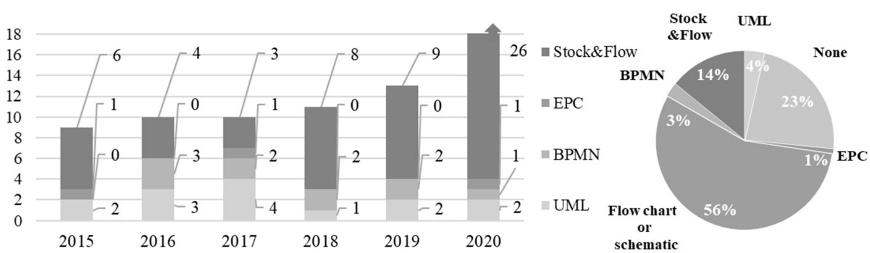

Figure 3: Notations used (multi. notations per article possible); Proportions of notations (rounded; 396 articles total)

Next, we looked at the correlations between simulation methods and the used notations, see *Fig 4*. Only one strong correlation between SD and Stock&Flow was identified (r $= 0.643 \mid p < 0.001$), which is due to the methodological relationships, explained in *Chapter 2*. Furthermore, there is a moderate negative correlation between DES (r $= -0.236 \mid p < 0.001$) and Stock&Flow, which is related to the previous correlation. However, one moderate correlation between DES and BPMN (r $= 0.209 \mid p < 0.01$) and a weak correlation between ABS and UML (r $= 0.106 \mid p < 0.05$) were also identified, indicating another methodological correlation. Thus, BMPN is often used to model processes within DES paradigms. In addition, many tools offer DES on the basis of BPMN, which also leads to a conclusive connection especially when using simulation environments that allow graphical simulation with

BPMN; like Di Leva et al. (2017) who used a framework called BP-M*. The use of UML for ABS can also be explained on the basis of the methodical relationships, because the object orientation of UML allows good representation of ABS models (e.g., Liu et al. 2019, who developed a use-case diagram to demonstrate an autonomous system in their ABS). As can be seen in *Fig 5*, UML was used in nine percent of the ABS articles, BPMN in eight percent of the DES articles, and Stock&Flow in 66% of the SD articles. The high use of Stock&Flow in the 90 HS can be explained by the share of HS with combined SD (see *Fig 4*).

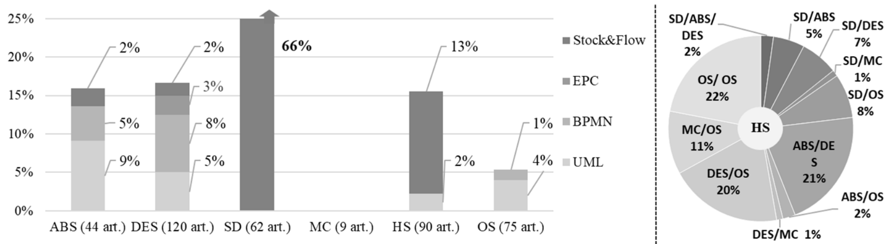

Figure 4: Notations in Methods (400 simul.); Combined methods in the HS (90 simul.)

6 Conclusion

This study conducted a wide-ranging literature review using publications from 2015–2020 based on six *business applications* and identified 83 simulation articles with notations from a set of 396 relevant articles. A total dataset of 1,068 articles was screened, including a forward-backward search for 40 articles.

In relation to **RQ1**, our results show that 20.96% of the considered simulations use a graphical tool (e.g. Stock&Flow) or a standard notation (such as UML or BPMN). The percentage of UML, EPC, and BPMN usage (excluding Stock&Flow and SD) was 8.5%. Among the articles dealing with P&L, the share of UML, EPC and BPMN usage was 7%. In comparison, Rosenthal et al. (2018) identified 38 notations in 300 articles in their review of process models (12.6%). If we look in vain only at the DES articles, then 15% of this article uses notations. Given the different observation areas and times, our result and those of Rosenthal et al. (2018) are comparable, particularly because our results assume a constant use of IS notation in simulations approaches since 2015. To answer **RQ2** we could show the clear connection between SD and Stock&Flow and also the connections between the simulation method ABS and UML as well as between DES and BPMN. A connection with HS and notations was not found; this is likely because there are too many different expressions of HS.

Our results are transferable to a wide range of simulation approaches due to the broad scope of our study. Moreover, they reflect current discourse on notations in simulation, which can provide future systematic guidance for scholars and developers opting to employ notations for increasing conceptual simulation credibility. However, our review is methodologically limited due to its restriction to *business applications*. Moreover, the classification of *business applications* and notations can only be carried out to a limited extent by means of a literature analysis; which offers limited insight into the underlying research and simulation development. For this reason, we could not determine how the authors proceeded in the development of the simulation and whether notation of the IS was used in the background.

Finally, more research on the use of notations in the simulation environment would be useful. Future studies should investigate why notations are used in some cases and not in others to clarify how standardization in the representation of simulation projects can be achieved; this will increase the quality and comparability of studies (Auf der Landwehr et al. 2020).

The analyzed, articles are available at: https://doi.org/10.25625/XFWDKB

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