RESEARCH-AGENDA FOR PROCESS SIMULATION DASHBOARDS

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ABSTRACT

The *European Conference on Modeling and Simulation* is a prominent but not the only conference showing possibilities and relevance of simulation. Meanwhile, it is an important field of research worldwide and current discussions about the *industry of the future* and especially the idea of *digital twins* for the simulation of forecasts in parallel to an existing reality increase its importance.

All these efforts led to highly elaborated simulation modeling methods and tools that can be applied to different fields from air traffic management to zoo building. However, based on conference participations, literature research, and conversations with other researchers and practitioners, we observe that simulations are by far not being used as often as possible in day-to-day business. And if they are used, typically individual software solutions are developed that can hardly be transferred to other applications. So, how can we reduce the barriers for using simulation?

Any simulation comes along with a profound domain knowledge, a modeling method, a tool for the definition and simulation of models, and the visualization of the simulation results. Different roles conduct these tasks: Domain experts deliver the domain specific knowledge and – as is the case for further members of staff – must be able to interpret the simulation results. Modeling and visualization experts develop the simulations but also deliver a proper presentation for the domain experts, probably without having a deeper understanding of these results. A decision on whether a simulation is conducted at all is made by management, possibly together with the information systems department. The latter roles need information concerning the benefits both in advance as well as in retrospect.

Since we mainly work in the field of process modeling and simulation with the aid of Petri nets for production and logistics, the above made considerations encouraged further studies on the usage of simulation with a special focus on dashboard visualization of the simulation results in this field. A holistic approach includes the process of simulation development and use. The research agenda for which a grant could be won is explained within this paper and may animate other researchers to participate.

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THE SIMULATION RESEARCH DILEMMA

A recent survey of 120 business decision-makers conducted in the DACH region yielded trend key topics – that is, not yet already establishing technologies – for companies in 2020. Regarding the actual utilization rate of some selected technologies in a direct process visualization context, metadata management leads with 27,3%, followed up by business activity monitoring with 17,5% and modeling digital twins for simulation of physical objects with 15,9%. (Roth and Heimann 2020)

In other words, around 70 to 85% of questioned companies do not currently utilize such technologies which leads to the question: What hurdles need practitioners to overcome in order to take more advantages from the simulation topic? We assume that – like it is the case for optimization – methods and tools are more in the focus of research than concrete applications or even an industrial usage of the methods which makes it hard for practitioners to apply them. Recent studies on optimization problems, for instance, demonstrate complex qualitative analysis and visualization results that are assessed with respect to their performance measures and indices (Koochaksaraei 2017). Although this is understandable from a research perspective, it does not help practitioners nor support the transfer into their day-to-day business.

We therefore advocate to embed simulation into a business perspective which has not been done sufficiently in the past. For example, the phases of a simulation study described in figure 1 ignore decisions on the simulation itself and does not explain the organizational roles involved in theses phases.

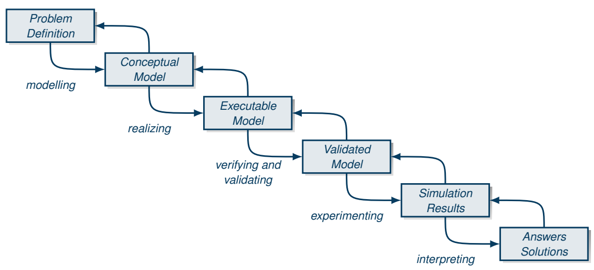

Figure 1: Phases of a Simulation Study adapted from (van der Aalst et al. 2010)

However, there is something else that matters with this phase model: It presumes that simulations are conducted for a singular purpose.

Actually, this is true for many cases like a simulation in advance of a technical construction of a production line. But especially in the cases of forecasting and digital twins, simulation models are needed to be executed on a regular base, for example at the beginning of each planning phase. Obviously, former simulation results should then have an effect on later executions. The simulation environment could become a learning system.

Moreover, the term *simulation results* used in figure 1 leaves space for interpretation. Of course, this is a mathematical result, but the way it is presented might have consequences concerning the conclusions drawn from it. Although van der Aalst et al. (2010) see the need for interpreting the result in order to have answers to a given problem, we consider it worthwhile to think about different possibilities to present simulation results. It might even be necessary to present them from different perspectives in a dashboard like manner.

The adapted visualization pipeline of (Schumann and Müller 2000) shown in figure 2 explains the steps in which a visualization is developed. The major steps are *filtering*, *mapping*, and finally *rendering*. In comparison to figure 1, this pipeline goes one step further by also integrating the simulation results and their interpretation by the user for whom the simulation is conducted as well as a feedback loop to the visualization.

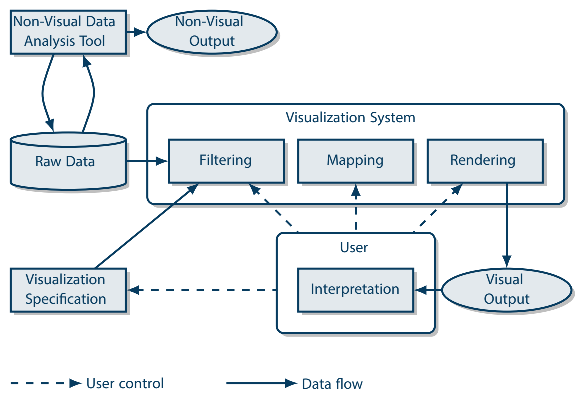

Figure 2: Extended Visualization Pipeline adapted from (Schumann and Müller 2000) based on (Robertson and De Ferrari 1994)

Visualization is meant to facilitate the assimilation of information and to compensate for the bottleneck in information processing. Through visualization, the viewer recognizes and understands connections within the data that would not have been recognized without visualization. Further, visualization can also be used to target the transmission of information.

A connection is built between insight, understanding, and explanation – also to third parties. Thus, visualization is a communicative process that needs to be constantly repeated and improved.

Although, in the last decades, many visualization systems enhanced their usability towards a better understanding of data, they are still difficult to use and are not always reliable, accurate tools for conveying information which limits their acceptance and use. (Telea 2015; Hansen and Johnson 2005)

The *Managed Simulation Process* (MSP) of figure 3 overcomes the limitations mentioned above. It integrates management objectives relevant at the beginning and for the economically successful completion of a simulation. The additional responsibility assignment matrix (also known as RACI matrix) shown in figure 4 includes the responsible roles for each activity of this process.

The MSP starts with a *decision* on whether a simulation is conducted at all. For this, a demand must be *recognized* first, followed by *choosing* a proper method and *selecting* a specific tool or consulting company. Finally, the simulation must be *approved*.

Then, the actual *simulation* is conducted which starts with an *analysis* and problem definition. Afterwards, the simulation *model* is developed (which of course may be a repetitive task) before the simulation can be *executed*. At the end, the simulation results have to be *validated* and probably need to be interpreted.

Visualization is a major outcome of a simulation. Following the simulation pipeline, the MSP considers the steps of *specifying* the intended output, *filtering* relevant data, *mapping* the data to interconnected observations, and finally *rendering* the visualization.

If simulations are conducted on a regular basis (for example for forecasts or production planning), the following steps should be iterated: First, the outcomes of the different simulation runs must be *monitored* and *reviewed* concerning their validity. Moreover, there exists a chance to *compare* the different simulation outcomes and to use former simulations to *improve* the model the simulation is based upon.

At the end, the economic outcome of the simulation must be assessed in a *control* phase. This starts with an (economic) *measure* of the improvement achieved by simulation, a *combination* of the findings with other possible approaches, a *revalue* of the entire result and an *established* routine (for or against) simulation.

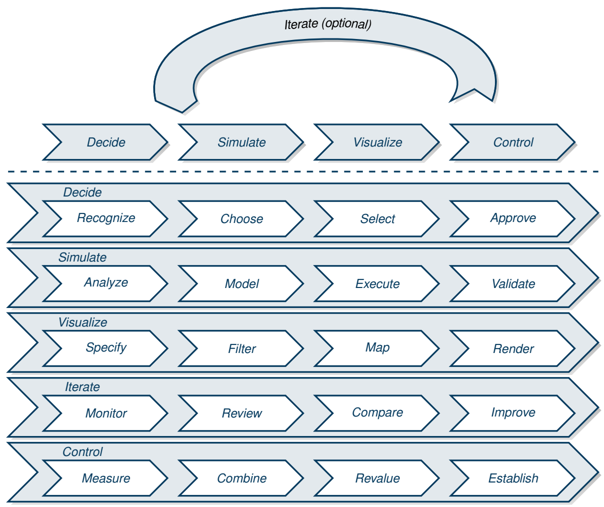

Figure 3: Phases of the Managed Simulation Process

Especially the RACI matrix uncovers the problem of establishing simulation as a regular routine in many corporations.

While management is not involved in the core tasks of simulation, it plays a major role at the beginning and the end of this process. If this is not taken into account, simulation might never be established as a method in a company. Especially a retrospective appraisal must not be forgotten, although this is typically not discussed in research papers on specific simulation methods.

We observe the following roles: *Domain experts* deliver the domain specific knowledge for the simulation and participate in the entire process. They must be the drivers for this process. *Modelers* and *visualizers* are the technical experts to perform the simulation. *Management* decides on whether time and money are invested for the simulation. Finally, the role of *procurement* might not be underestimated.

		Domain			Simulation	
		Management	Procurement	Expert	Modeler	Visualizer
Decide	Recognize	I		R		
	Choose			R	C	
	Select		R	R	C	C
	Approve	R	I	I	I	I
Simulate	Analyze			R	R	C
	Model			C	R	R
	Execute			R	R	R
	Validate			R	R	R
Visualize	Specify			R	C	R
	Filter			I		R
	Map			I		R
	Render			I		R
Iterate	Monitor			R		
	Review			R		
	Compare			R		
	Improve			R	R	R
Control	Measure			R		
	Combine			R		
	Revalue	I		R	I	I
	Establish	R		I		

Figure 4: Responsibility Assignment Matrix of the Managed Simulation Process

In the following, we use this phase model to explain each step of a simulation and finally our new research approach we want to share with colleagues.

A DEMAND FOR SIMULATION

In order for a simulation to be conducted, *domain experts* must notice a demand for information that cannot be gained by other, more direct means, or alternative approaches would be much more expensive than conducting a simulation.

Choosing an appropriate method is a task for these experts together with *simulation modelers*. The term simulation modeler shall distinguish this role from other modeling experts who “only” develop conceptual models for explanation or visualization of a specific topic without claiming for simulation as a mathematical approach.

The tool selection necessitates *visualization experts* as a further role: they advise about the feasibility of different solutions with regards to the simulation goals.

The *procurement* department sets the financial borders for the investment with respect to the demands as shown by the domain experts. It might also influence the tool selection with respect to standard vendors of a company.

Lastly, the corresponding *managers* need to approve of the planned simulation project and release it.

THE SIMULATION MODEL

Domain experts, modelers, and visualizers are responsible for model and simulation execution. Cooperation among them is crucial for the success of a simulation project:

- As domain experts probably lack formal experience regarding simulation methods, they formulate the simulation goals and need to fully understand what the model does, what it does not, and what can be deduced.
- The modelers need a thorough understanding of the formal aspects of a system but may lack knowledge concerning its application or the practical impacts of the simulation results.
- The visualizers need to understand how the simulation results may be represented without having detailed knowledge on how to gather the (mathematical) simulation results.

Modeling and simulation methods can be classified by different aspects such as whether it can be conducted by an algorithm or not. Computer simulations may have several, sometimes contradictory goals that necessitate different modeling approaches. (Winsberg 2019)

If random elements have to be accounted for as for example customers entering a store in a queue, *non-deterministic* or *stochastic* models are used.

Deterministic models are used if a definite causality is given like in systems following natural principles. (Müller and Pfahl 2008)

In *chaotic* systems – which nonetheless are still deterministic – the simulation outcome varies strongly even on small deviations of the start setting (Bishop 2015). They may be of interest for scenario forecasts.

Dynamic simulations can be influenced during runtime – the simulation progress may depend on more than the factors given at the start, for example interspersed production failures or machine defects. This opens the possibility of testing adaptation capabilities. *Static* simulations allow for directly examining the implications of distinct start settings as constraints don't vary between different runs. This distinction can also be formulated by referring to the time of the last usage of new input data. (Müller and Pfahl 2008)

In static systems, *invariant* data is hardcoded in the model while *preprocessed* data is input at startup. Dynamic systems also use these data sets in addition to *runtime* data such as user input or sensor readings.

Discrete simulations run in time increments (or steps) of fixed length. A special case are *event-discrete* or *event-triggered* simulations where the steps don't have predetermined intervals. Rather, a new system state is computed on the moment of change.

In a *continuous* model, there are no steps whatsoever. Instead, the system's state gradually changes over time. This approach is more common to flow production or physics. (Müller and Pfahl 2008)

Finally, simulations may be distinguished in *quantitative* models – yielding numerical values – and *qualitative* models – with results being generally non-numerical. (Müller and Pfahl 2008)

As these classifications aren't mutually exclusive, models of interest normally combine several of the mentioned aspects, resulting in what is sometimes called hybrid models. However, this term is not uniformly defined and should be treated with care. (cf. Müller and Pfahl 2008; Brailsford et al. 2019)

THE MEANING OF NUMBERS

To convey information in a clear, concise and quickly accessible manner, different methods can be employed. Beside textual descriptions or tables, for example graphs and diagrams are often used. Obviously, the visualizers play the most important part in this step while, beyond the specification, the domain experts only have a passive role. Regarding the specification, knowledge of what is important for the real system and what is possible as output from the model are needed.

Visualizing the results

Visualizations provide high-level information about underlying data and (also simulated) processes. This data conveys insight into diverse applications such as procurement, production, computed on or distribution

To create a pertinent visualization of a given data set, the following aspects must be considered:

- The principles underlying the modeled real system.
- The presentation of the simulation models such that the domain experts can validate their correctness.
- The possibility to retrace the simulation in manageable amounts.
- Structure and quality of the input and output data.

But what exactly are the requirements that lead to a good visualization and which visualization types are suitable?

First, one should bear in mind that a short *text form* might sometimes be the better choice compared to a graphical visualization, since they do usually consume more space. Also, *tables* are still suitable in many situations, cause they both give an overview and support picking relevant data. A good visualization system is more than a mere presentation system in that it offers the possibility to uncover the contents. This is what is actually intended by figure 2.

According to the MSP, domain experts and modelers develop the data yield from the model and domain experts and visualizers do specify the visualization with the goal to transform simulation data into visualizations.

The remaining steps of this phase are at the responsibility of the visualizers with the domain experts being informed about the proceeding.

Mapping is a key element of visualization: this step converts invisible data into visible information. Mapping sets the visual attributes that encode the actual data. Rendering determines the remaining visual attributes that the visualizer can set. The final image is rendered using the processed data. (Robertson and De Ferrari 1994; Talea 2014)

Nowadays, countless variations of *diagrams* exist and with the upcoming data mining discipline their number seems to increase daily. Choosing appropriate diagrams is an art and a serious discipline which needs a lot of experience at the same time. This may be explained with the aid of some well-known diagram types:

- Point diagrams are used to depict relationships between categories.
- Line plot diagrams (cf. figure 5) are suitable to represent continuous data, but may confuse viewers if their axis-inscriptions are non-linear.
- Slope charts connect two comparison points in different categories.
- Bar charts are easy to read, especially if the x-axis-value is equal for each item, however visualizers must carefully decide on whether they draw them vertically or horizontally.
- Stacked bar charts may represent several categories at once.

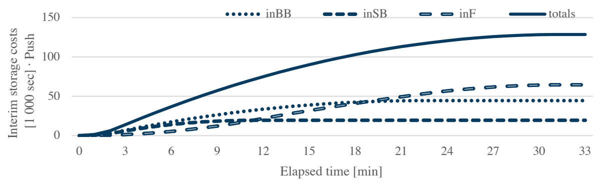

Figure 5: Example of a Line plot: Inventory Costs for Storages and Accumulated Totals (Simon et al. 2020)

Taking the following factors into account typically has a positive effect on a visualization:

- The degree of prior knowledge of involved persons.
- The visual abilities (or limitations) of the viewers and their general preferences.
- Using metaphors of the target discipline.
- Specific nature of the representation medium.

Obviously, not every visualization is target-oriented and by wrong types of visualization the simulation's audience may be lost. According to Nussbaumer Knaflic (2015), the following should be taken into account:

- Avoid pie charts, since their segments are difficult to compare for the observer, especially if they have almost the same size. Pie charts can often be replaced by bar charts which overcome these problems.
- Also, in donut diagrams, particularly if they make use of 3D effects, the different segments are difficult to compare.
- A second y-axis may cause confusion, if different areas are depicted by the x-axis. Simple labels or splitting up the information over several graphs might be better solutions to this problem.
- Lastly, avoid confusing colors, as shown in figure 5; this will be discussed later on.

There exist several other forms of diagrams which might all be useful in a specific context. An example unknown to a broader audience is the chord diagram which represents large amounts of data and their relationship to each other. (Jalali 2016)

Figure 6 shows an example of a chord diagram connecting several points of cumulative waiting time calculated by a Petri net simulation of a production process, actually the same process of figure 5.

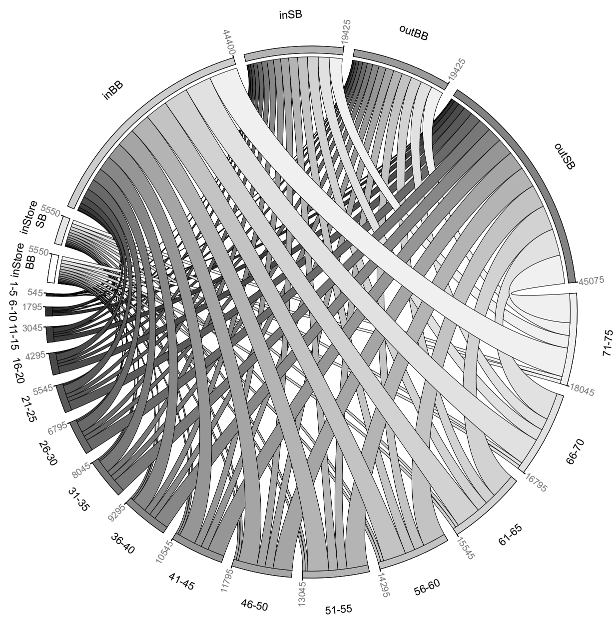

Figure 6: Example of a Chord Diagram: Waiting Times of Items in Different Settings (Haag et al. 2020)

This representation motivated to initiate the project described at the end of this paper to systematically do research on the visualization of process simulations with the aid of Petri nets.

Just the right visuals: Dashboards

The main goal of a dashboard is to create a coherent and coordinated picture that enables people to see and understand data. Dashboards convey data to ease their comprehension. Hereby, it is the aim to balance this goal with regards to efficiency and available time. On the way to effectiveness, accurate and functional thinking should be pursued (cf. Few 2013) with the option of presenting the data elegantly. The following ideas and criteria are helpful on this path (Wexler et al. 2017):

- Like in many other occasions, start with the definition of the specific goal of a dashboard to be developed and think of a user-friendly realization of this goal. Often, the possibility to adapt the dashboard for specific user needs is beneficial.
- Design a grid view which serves the purpose of clarity best, since cells of the same size make it easier to keep track of the data.
- Another design principle is described as breathing, a form of responsiveness.
- A purposeful use of color is crucial for users. Color can be a tool to determine a ranking, to define an area around a (neutral) center (e.g., the average), to separate categories by color or to set certain highlights.
- Also, different font sizes help users to keep a priority ranking. Simple numbers or statements as headlines can transport a clear message of the dashboard.
- Since dashboards are objective of discussions between different roles in a companies' organization, they must withstand different soft factors as well as subjective preferences.

In summary, a visual representation of monitoring data should be created with as little effort as possible, but this must lead to the best possible understanding for the majority of the target group consisting of management and domain experts.

REGULAR IMPROVEMENT BY SIMULATION

If simulations occur on a regular base, for instance in a digital twin of a real production environment to decide on different production strategies instantly, optimized simulation execution times become more and more important. The simulation must run fast enough to deliver results in a given reaction time. If simulations are used in planning processes instead, it must be faster and/or cheaper than other approaches, regardless of users' wishes to receive a quick simulation result.

Moreover, if simulations are executed and their results are interpreted on a regular base, a learning process should start with respect to the simulation itself. This is what the *Iteration* phase of the MSP expresses.

The iteration phase starts with observing the simulation, its results and interpretation which should be automated by a *monitoring* system. A deeper understanding of the simulation results can be gained from the current and former simulation runs which have to be *reviewed* and *compared*.

The probably most important step within this phase is *improvement*. Regular improvement cycles allow a constant adjustment of input data, simulation, and output data. A team consisting of domain experts, modelers and visualizers can use the lessons learned to improve the simulation and visualization system.

Long term, this procedure eliminates sources of variation in forecast or production data. Companies may abbreviate this phase when a sufficient level of quality is achieved.

CONTROL OF SUCCESS

Simulation is not an end in itself and the MSP therefore includes the management perspective at the beginning and the end. Ideas for a retrospective consideration of a simulation can be taken from the Control phase of Six Sigma projects. Like in Six Sigma, also simulation is intended to lead to an economic improvement.

Also, for this final phase, a visualization is crucial, however on a different level. It is not about the visualization of simulation runs but on the effect the conclusions of a simulation have on the simulated objective, in our case a business process in production or logistics. If, for instance, the simulation has the objective to reduce the throughput time of a production line, an economic result might be the new customer group that can be attracted by this.

A lot can be learned from Six Sigma at this point since also this approach considers process performance and process capability. Measures like defects per unit or the process capability index can be used.

What is crucial here is to carry out an ex-ante and ex-post analysis. An improvement (or probably a worsening) must be visible in a strategic dashboard, it must be verifiable and sustainable. The resulting improvements have to be controlled actively. (Tavasli 2007)

THE PATH TO THE GOAL

In order to deliver practitioners with suitable visualizations, a fitting modeling environment should provide possibilities for a wide range of application purposes. As theoretical foundation, we chose Petri nets for the following reasons:

1. Petri nets are *semantically clearly defined*, *well researched*, and *analyzable* with the aid of the large toolset linear algebra provides.
2. Petri nets provide a *high modeling power* and can be used in *process contexts*.
3. We have decades of *experience* with modeling and simulation using Petri nets.
4. With the Process-Simulation.Center (P-S.C), a web-based modeling and simulation environment based on Petri nets, an *advanced tool* exists that doesn't depend on commercial third-party integration.

Within a project it is the aim to do deeper research concerning the two phases *Simulate* and *Visualize* of the MSP. Since our simulation method is Petri nets, the goal is described as follows:

Create expressive visualizations of reachability sets and graphs of high-level Petri nets or excerpts therefrom both at runtime and at the end of the simulation.

To achieve this, we have established the following *research agenda*:

1. *Literature research*: Identify the state of the art of research on visualization of reachability sets and graphs of high-level Petri nets.
2. *Scenario creation*: Establish models of real-world scenarios based on logistics and production.
3. *Dashboard creation*: Identify frequently used key performance indicators and suitable visualizations. Adapt these visualizations for use in dashboards.
4. *Reference modeling*: Develop reference models for the automated and dynamic integration of visualizations and dashboards into simulation models. At this stage, applications for third party funding should be prepared.
5. *Prototyping*: Establish prototypes for the developed reference models. At this stage, applications for third party funding should be submitted.
6. *Transfer*: Infer research results to (regional) partners and enable them with the first iterations of usable prototypes and tools.
7. *Stabilization*: Expand on available simulation scenarios from other industries and departments. Stabilize the implementation.
8. *Evaluation*: Evaluate and document the results and communicate them with stakeholders and academia.

As first partners in both academia and economy have been found already, work on the first step has begun by now. We plan for the reference modeling to commence at the end of this year.

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