

# Real World Case Study To Teach Simulation

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**Abstract**—Classical lectures, supplementary reading and best practice demonstrations (often) form the core of traditional teaching. This is appropriate for the education of syntax and semantics of a process modelling language and to conduct simulation. They are, however, inappropriate to convey pragmatics. But exactly this is needed to stimulate discrete thinking and creativity, skills required in business for the challenges of digitalization in a professional environment. This paper is about using a real world case study to teach modelling and simulation of processes and to facilitate students with the ability to find solutions on their own. Students are confronted with the challenges as they actually occur. They have to face the needs of stakeholders which means that in addition to the actual simulation model, also an interface must be developed for the input of the simulation parameters and a dashboard for the presentation of the simulation results. The danger of this approach is to overburden students with the multitude of tasks required for a solution, potentially leading to a failure of the teaching process. At a glance, the paper summarizes the teaching material developed and the experiences made so far with this approach.

**Keywords**—Interactive Education; Real World Case Study; Modeling; Petri Nets; Simulation.

## I. INTRODUCTION

The learning pyramid as depicted in Figure 1 classifies different teaching approaches and the corresponding learners' retention rates. The most active and participative methods show the highest learning coefficients [1]. The more teaching concepts shift to problem solving, the higher the average retention rate of the method is.

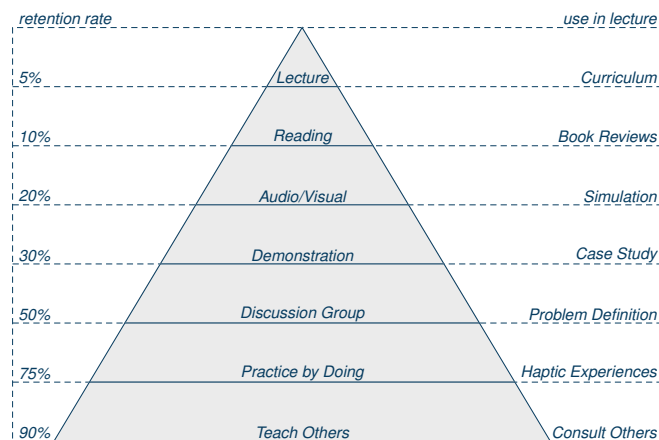


Fig. 1. Learning Pyramid.

Each layer of the pyramid follows a different didactic approach and indicates which retention rate can be expected from the students [2]. This paper is about a method to increase the retention rate of case studies by using a real world example of a consulting project the authors have conducted. The aim of this approach is to convey the complex reality into teaching. With this way of teaching, the authors want to motivate the students to answer the question of why they should learn a specific topic: the answer is to be able to satisfy the customers' needs later on in a business context.

The wish to offer such kinds of lectures results from the very specific idea of Universities of Applied Sciences (UAS) in Germany (like Hochschule Worms). They differ from „Classic“ Universities (CU) as they are also known in other countries.

In addition to scientific reputation, UAS lecturers must have practical work experience and circulate this hands-on knowledge to their students to prepare them for an industry career. Further, they are encouraged to maintain industry contacts to exchange ideas, keep their own research and teaching up to date, and conduct practical industry research projects. At the other end, CU professors would rather conduct fundamental research, which is also reflected in their teaching. Boundaries between the two types of universities are fluid [3].

UAS tend to a learning environment with small class sizes, are often more hands-on, and include practical projects and group work. The Hochschule Worms, for example, claims these ideas in its strategy: research and practice guide the teaching to increase competence in students' careers and academics [4]. The aim of this approach is to expand the students' knowledge and enable them to solve problems on the basis of the newly acquired knowledge [5].

Several teaching concepts have been presented at the SIMUL 2022 conference ([2][6]), sparking an intensive discussion about what lecturers do to improve their lecturing: What further interactive methods for teaching modeling and simulation are needed? This contribution continues the discussion started one year ago.

New ideas to develop teaching further is discussed at the example of process management as an important pillar in business informatics studies. Process models help to understand, optimize and automate processes in detail. Thus, they are an essential foundation of the fourth industrial revolution for the digital transformation of companies. However, books and other classic teaching media are only partially successful in conveying the special features of

processes within dynamic systems. Simulation based teaching combined with a real world case study has the potential to lift the teaching success to a higher level.

A real world case study on process modeling and simulation which also includes requirements of practitioners offers the chance to develop the following competencies [7]:

- 1) Systems Competence
- 2) Decision-making Competence
- 3) Future & Design Competence

The following Section II outlines the real world case study. Then, Section III explains the shift from the real world to a digital world. Afterwards, Section IV shows how to model processes and design an interface to control the simulation. The actual simulation is discussed in Section V. The translation of the mathematical results into a dashboard is explained in Section VI. A conclusion ends the paper.

## II. REAL WORLD CASE STUDY

Modeling and simulation play a crucial role in business and especially in logistics, but need skilled people who are able to develop and run the models. Future-oriented skills must be taught for this [7]: *System Competence* is an indispensable precondition to conduct process simulation. It trains students to understand systems and their interdependence. Part of this knowledge is how to design, implement and monitor processes. This competence goes hand in hand with the *Decision-making Competence*. It involves considering different alternatives against each other. As soon as students model and simulate processes, they develop the competence to decide and act responsible. Finally, simulation trains the willingness to change and to think ahead as envisaged in the *Future & Design Competence*. Based on simulation, students can further develop scenarios and creatively solve problems. Considering the learning pyramid of [1], it is important to embed these skills into an experience-based learning environment, such as case studies.

In principle, companies use case studies to explain their products in order to market them afterwards. Those studies show the impact of commerce on the end result and tell how real customers overcame their problems with the product or service offered. In the context of teaching, lecturers successfully apply such aspects as storytelling, overcoming problems, or cause-and-effect principles in teaching. Real world case studies allow students to recreate challenges they will face in their future work [8]. The gap between theory and practice is closed [9].

Real world case studies are discussed in literature several times like in [8], [10], [11] or [12]. They are characterized by the fact that concrete problems are conveyed to students for analysis, open discussion, and final debate. It requires five steps to design a case study [13]:

- 1) The focus of the analysis is the actual situation.
- 2) The academic focus of knowledge must be put into action.
- 3) Students are intellectually and emotionally involved in the method.

- 4) Lecturers act as facilitators and must be both teacher and practitioner.
- 5) Students develop an interdisciplinary understanding of the problem.

The actual situation in this case study chosen by the authors is as follows: Infraser Logistics (ISL) at Industriepark Höchst expands its logistics services for the chemical, pharmaceutical and healthcare industries [14]. A new warehouse is built and the operation starts. Safety requirements have top priority.

With the new warehouse, ISL sets new standards in the efficient, largely digitized storage of highly dangerous goods. To meet these standards across the industry, the industrial park provides information concerning the pilot phase of the warehouse to this real world case study. Only concrete specifications of transport times within the warehouse are dissembled with respect to the competitive situation.

The goal of the conducted modeling and simulation is to objectify assumptions made during the conceptual phase. ISL wants to use simulation to find its own best practices and seeks verification from external parties. The core task of the case study is to model and simulate the core processes in the warehouse. Among other things, the following data is provided for this purpose:

- Space for more than 25,000 pallets
- 9 separate warehouse sections
- Storage of multiple LGK storage classes
- A wide temperature range from -6 to 20 degrees Celsius in the different sections of the warehouse [14]

Some of the data is publicly available in press reports or on the website. All other sensitive data needed to successfully model and simulate the processes are known to the authors but had to be modified for this publication for the above mentioned reasons to guarantee the trust of the industry partner.

## III. FROM REAL TO DIGITAL WORLD

The first step in modelling a real world warehouse is to collect the relevant real data and to build a digital shadow of the warehouse which can be simulated [15]. The digital shadow serves as the overarching concept. It does not only map real processes into a virtual world but can also use the real world data as input for the simulation.

The first choice to be made is that of an appropriate modelling language and simulation environment. In this course the choice is done by the lecturer in order to synchronize the individual learning processes of the students' groups.

Petri nets have been chosen due to their mathematical basis. They differ from other languages in their possibilities for analysis, simulation and immediate feasibility in a target system. A suitable tool for this is the *Process-Simulations.Center (P-S.C)*. In addition to its already presented features [6], the tool's connectability to external data has been expanded. By entering data in a customer-specific input mask, it is possible to directly access a place in the Petri net model of the warehouse, as shown in Figure 2.

As already mentioned, the case study contains sensitive real world data. Therefore, access and visibility must be limited,

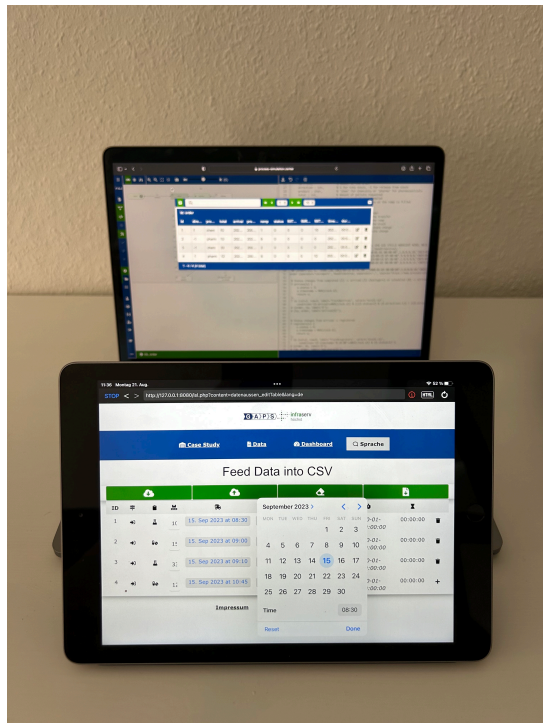


Fig. 2. Interface between Real World and Digital World.

especially for sensitive customer data. Here, the *P-S.C-Cloud* as well as the multi-client capability of the tool helps to manage security issues [6]. Sensitive input data and simulation results can be stored on in-house servers independent from the *P-S.C-Cloud* as explained next.

The close collaboration of real and digital world is shown in Figure 3. The dashed line shows the interface between the local UI of the end-users (of the partner company or the students) and the *P-S.C-Cloud*. This interface allows to drive the simulation with real world data in consulting projects and with modified data during lectures. The latter is defined in a way that still gives the students a comprehension of the entire system. In consequence, as the modelled system becomes more complex, the skill requirements of the students increase.

The phases of the interaction between the local UI and the *P-S.C* can be explained as follows:

**Feed:** The process starts with the end users of the simulation, i.e., engineers or during operation the warehouse manager or students who play this role in the lecture. They use a customized input mask to enter order data and available resources for a simulation run. All they need for this is a browser on a computer or even an iPad like the warehouse employees use on the shop floor. This data is stored in a CSV file on a company’s local server. The *P-S.C* uses a link to load the data into the simulation.

**Run simulation:** The simulation is conducted on the base of the linked input data. If necessary, the link to the input data can be hid from unauthorized users. The input data is loaded

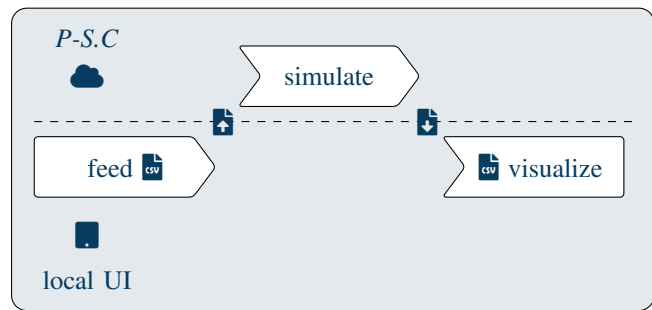


Fig. 3. Real World vs. Digital World.

directly into the browser of the end user, i.e., the *P-S.C-Cloud* does not get in touch with this data. After the simulation has finished, an automatic download is started and the users can store the simulation result on their local computer.

**Visualize:** The downloaded CSV file in turn can now be uploaded again in the local UI or another business intelligence application. The simulation results are visualized in a way that supports the end users to come to a decision on how to proceed in the real world.

In guided student projects, all of the following aspects can be discussed and worked on, which are formulated as todos:

- 1) Identify the process to transfer pallets into and out of the stock.
- 2) Specify the data necessary to control this process.
- 3) Develop a data driven model for the process.
- 4) Develop a user interface to administrate the simulation input data.
- 5) Develop a user interface to visualize the simulation results.

Different abilities and skills are demanded for this complex list of tasks: the students should have previous knowledge and practical experience in programming. They should be able to develop user interfaces and visualize data in diagrams. Hence, the described tasks are part of an advanced concept. In the context of lectures, a high level of training of the students as well as assistance for a satisfying solution is required. Once the infrastructure depicted in Figure 3 has been developed, different scenarios can be simulated and suggestions to improve the real world process can be systematically be derived from the simulation run.

#### IV. FEED - PROCESSES AND DATA

According to the list of activities named in the previous section, the work on the following three activities merges together into one large task:

- Identify the process to transfer pallets into and out of the stock.
- Specify the data necessary to control this process.
- Develop a user interface to administrate the simulation input data.

The goal is to have an end user friendly interface to administrate the simulation relevant data. This data will control the simulation run. The virtual order will then run through the simulation model and its processing proceeds. This progress needs to be documented such that there must be a data field within the order that codifies the current state. The naming of these states is deferred to the next section.

The second aspect is that there are two major movements within a warehouse: goods are transferred to stock, inbound, and are released from stock, outbound. Hence, also an attribute is needed to codify the direction of movement. Finally, since the simulation result has to be visualized in a dashboard, an attribute must be reserved to document the duration of each task.

Further attributes are those that control the process flow like the arrival time of trucks, the loading ramp to choose, or the staging time for material. To find these attributes, students read through the case study and conduct on-site (or virtual) interviews. A challenging task is to determine a good degree of detail. For the learning success on understanding the complexity of systems, it is crucial to maintain authenticity.

Subsequently, the focus lies on the interface. It is important to stay close to the customer's needs. The interface of the application is initially programmed bilingual in English and German. The input mask shown on an iPad in Figure 2 and as a screenshot in Figure 4 are examples on how the user interface may look like. Here, nudging and the poke-yoke effect are of great assistance. Both ensure that only target-oriented and required data are entered by the users.

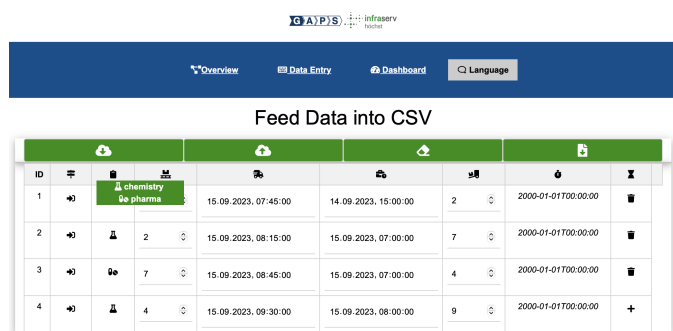


Fig. 4. Feed Data into CSV.

The input mask has a variety of functions:

- ⬆️ Load the last uploaded data
- ⬆️ Upload data (e.g., to the *P-S.C-Cloud*)
- 🗑️ Remove data
- ⬇️ Download data locally
- ⊕ Add a data set

The CSV file to control the *P-S.C*-simulation can be generated with this user interface. For this, a place representing the orders of the warehouse are typed in a similar way. At the beginning of the simulation, the data can be loaded from a (company's) web server using a link to the file.

## V. SIMULATE - SIMULATION TO CSV

The results of the last phase, interface and data structure, are now used to develop the simulation model. This work package includes several student activities from Section III. The data structure plays a crucial role, as it links the phases. The starting point here are also the real processes to inbound and outbound pallets in the warehouse. First, the process steps need to be identified in order to reduce the complexity of the overall processes to single states. The different states are shown in Table I and Table II.

TABLE I. STATES WITHIN THE ORDER PLACE DURING INBOUND

State	Description
<i>scheduled</i>	Order booked into LAP
<i>arrived</i>	Truck arrived at warehouse
<i>registering</i>	Truck is registering
<i>docking</i>	Truck at ramp
<i>unloading</i>	Truck unloads pallet by pallet
<i>undocking</i>	Truck leaves ramp
<i>leaving</i>	Truck left ramp
<i>departed</i>	Truck left yard & Order released
<i>storing</i>	Goods are being stored
<i>finished</i>	Goods are in storage

TABLE II. STATES WITHIN THE ORDER PLACE DURING OUTBOUND

State	Description
<i>scheduled</i>	Order booked into LAP
<i>staging</i>	Goods are taken from storage
<i>completed</i>	Staging is completed
<i>arrived</i>	Truck arrived at warehouse
<i>registering</i>	Truck registered on the yard
<i>docking</i>	Truck arrived at warehouse
<i>loading</i>	Truck is loaded pallet by pallet
<i>undocking</i>	Truck leaves ramp
<i>leaving</i>	Truck left ramp
<i>departed</i>	Truck left yard

Besides the state changes of the orders the execution of the orders is controlled by the available resources, such as type and kind of forklifts. In ISL's new warehouse, there are two types of forklifts - *SGS* for high-bay movements and *VHS*, which move on the shopfloor. These forklifts add more states and transitions to the Petri net. Forklifts remove the goods from the truck, transfer them from the ramp to the staging area, and finally via the transfer area into the high rack.

Such state transitions involving multiple resources are displayed in Figures 5 and 6. Both figures are parallel finite-state machines with prioritized resources. The previous tables, but also the finite-state machine, help during modeling to become aware of the individual states of the orders, forklifts and other resources.

All forklifts, especially *VHS*, are in a competitive situation with each other. The allocation takes place as seen in the finite state machine at state *i5* for inbound (Figure 5) and state *o8* for outbound (Figure 6). Further, the transition *next*, shown in Figure 7 organizes and sorts the orders according to

the requirements of the warehouse managers. The data of the orders as well as the resources control the processes in the simulation.

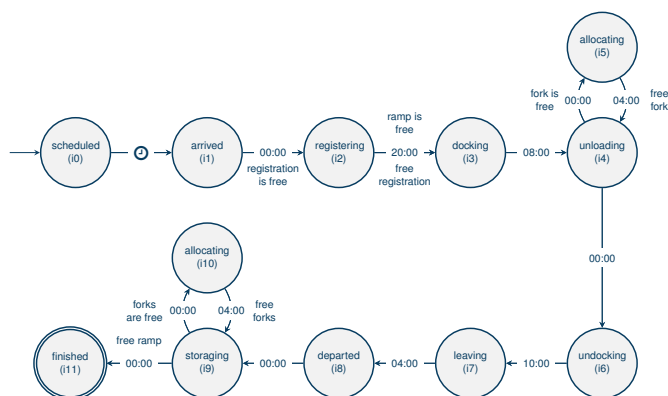


Fig. 5. Finite-state machine - Inbound.

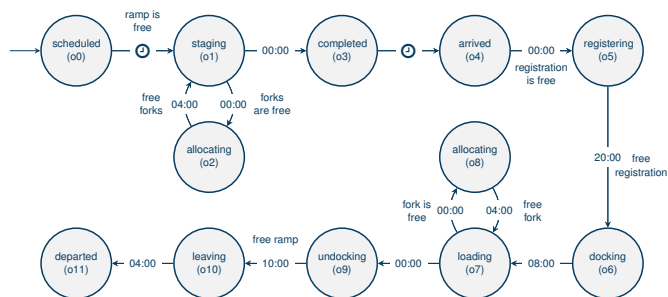


Fig. 6. Finite-state machine - Outbound.

A central clock synchronizes the activities as already described in [16]. This clock increases only, if all activities for a specific moment in time have been finished. The time at which an specific state transition is conducted is documented within a timestamp.

Figure 7 shows the setup of the Petri net and the clock mechanism at the same time. While the simulation runs, the orders change. Each change is copied into a protocol file, also in CSV-format. And this file is the input for the next step.

### VI. VISUALIZE - CSV TO VISUALIZATION

This final step completes the students' work. This step involves the development of a user interface to visualize the simulation results. Firstly, students draw insights from working with the project partner, as well as its real world challenges. Secondly, part of the education includes research in professional literature. Third, students learn with each model or dashboard they create. For example, the students are sensitized to choose the right format (16:9 or 9:16) or provide the most accessible frame, such as a CSV file to enter, process or visualize data. Practice literature like [17] clearly elaborates on the benefits and features of useful dashboards: dashboards serve to create a coherent and coordinated picture that allows users to see and understand data.

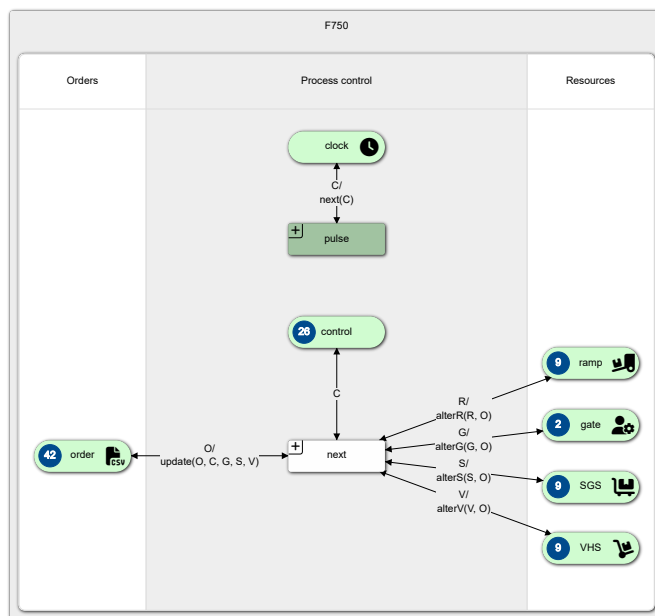


Fig. 7. Screenshot Petri net model by P-S.C.

On this basis, the dashboard of Figure 8 offers a step towards more objectivity and thus addresses the needs of the project partner. In addition, the dashboard now unites all parts of the warehouse - from registration to the high-bay warehouse. Therefore, this dashboard is the evolution of the last dashboard shown in [6].



Fig. 8. Interactive Dashboard.

The strategy behind this dashboard is that all information is visible in one place. It combines recognition and objectivity: users have to recognize their processes and the orders flowing along these processes. Symbols within the dashboard help to keep track of the things. With a rising complexity, these additional symbols might deviate from what is important.

Further Few (2013) reminds to design dashboards, such that users are able to understand and interpret the data - this is more than just to see it [17]. Based on this, the authors recommend that students do not visualize the movement of forklifts and trucks as described in [6] or as is popular with 3D animation software. Such animations also became less important for the

project partner as the project progressed and the dashboard could be observed along with the real world as its shadow.

The board can be divided into several parts:

- An interactive control panel is located at the top left. Users may control the speed of the visualization, or pause it at interesting moments. Further aspects like opening hours for externals, closing times, preparatory times can be controlled here.
- Below of the control panel, an analytic's board shows various statistics concerning the processes like staging time over the period of a work week. This information can be presented in different types of charts.
- The remaining areas of the dashboard belong to the different areas of the warehouse, from registration to high rack. Chemical and pharmaceutical goods are separated. Within each area, the amount of disposable is shown. When the visualization is started, the staffing of resources and their allocation by orders is presented over time.

The remaining area presents the following information:

- Ramps quantity and allocation
- Forklift quantity including buffer space
- Parking slots for waiting trucks
- Truck load limit
- Number of employees for registration

This setting is ideal for both, the employees in the company and the students, to "play" with the data and to observe how the performance of the warehouse changes with changing capacities of the various resources. Resources that are underutilized or bottlenecks can be identified.

## VII. CONCLUSION AND OUTLOOK

Taking a real world scenario and putting it into a classroom is a challenging task. Details hinder the students from having easy and simple solutions. But this experience is very important for young people being prepared for the challenges of a digitalized world.

The case study helps to develop critical competencies:

- Understand the benefit of modeling and simulation.
- Build models of the real world that can be simulated as their shadows.
- Understand the purpose of a valuable dashboard.
- Learn how to design a dashboard.
- Link a dashboard with the simulation results.
- And learn how to explain each single step.

The authors had to recognize that only the best Bachelor students were able to follow the entire story. And even using transformer AI-technologies do not help to ease this task at the moment [18]. For this reason they do not plan to complicate the scenario and simulation further more.

The next objective is to publish the use case in the tutorial to the *P-S.C.*, and to make it accessible to a broad learning and teaching community in modelling and simulation. The funding for this project will end by the end of 2023. It is planned to finish this work then.

## ACKNOWLEDGEMENT

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