Industrial Methods and Digital Tools for Craft Professionals – A Use Case Deploying Discrete Event Simulation and Virtual Reality

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Abstract. This paper presents an integrated approach to explore human factors in the craft sector. The embedded use case consists of craft workshops being 3D-modelled and simulated so that different scheduling rules can be deployed. The connected VR visualisation allows craft professionals to experience scheduling rules and their impact on different performance measurements in an environment intuitively resembling their actual workshops. The lessons learned from the simulation modelling are collected to be presented as a use case. A modular approach appears to be beneficial for the simulation modelling, offering flexibility and pragmatism but detail where needed. Apart from this anecdotal evidence, the study is accompanied by interviews. These are analysed based on abduction grounded theory which combines a strong focus on the actual corpus of qualitative data but considers theoretical foundations, when appropriate. This paper presents the study design as it has not yet been conducted completely but is ongoing.

Introduction

Industry 4.0 is a well-known term for production scientists and practitioners. However, the typical craft workshop is usually only partially, if at all, automated. While the selective use of automation can be justified by smaller production quantities and lower economic efficiency, such argumentation cannot fully transfer to digitisation trends. Many Industry 4.0 solutions had a strong technical focus. In contrast to that, most recent approaches, with the label Industry 5.0, pay more attention to human factors in the production environment [1, 2]. This may offer connecting points to the value creation in the craft sector.

One of the tools used in this context is discrete event simulation (DES) to model and simulate material flows through the production facility. DES is linked to the term digital factory. For example, it is used to virtually check production layouts for both new and replanned of systems or production scheduling. In contrast to that, the craft sector lags behind in applying digital tools. However, the requirements from both areas show certain similarities, as both value on-time delivery, throughput, capacity utilisation, lead-times etc.

1 Research Context

Compared to industrial value creation, increased labour productivity has been accomplished only to a lesser extent in the craft sector. Among other things, crafts are characterised by the fact that tools are operated manually. In contrast to that, industrial processes are mostly characterised by machine-guided tools. Ancillary processes, however, are not covered by this distinction but are similar to those in the industrial sector. Productivity describes the relationship between input factors and output over time, which is closely linked to the term technology from an economics point of view. New technologies are usually described by the term innovation. This section presents a brief introduction to the current state of the art for craft research, innovation diffusion, technology acceptance, simulation, and virtual reality (VR).

1.1 Craft Research

The craft sector is multifaceted and almost exclusively characterised by mostly small and some medium-sized enterprises [3]. Crafts account for 12.4 % of employment and 25 % of apprenticeships in Germany. Roughly 8 % of Germany's gross domestic product (GDP) is generated in the craft sector [4]. With the disproportionately large share of apprentices, it can be assumed on the one hand that there is sufficient digital literacy potential [5]; on the other hand, that the integration of digital content into training is of great significance [6].

Compared to enterprises from the industrial sector, digital tools are used less intensively in the craft sector [7]. The difference and the need to catch up in terms of digitalisation, has already been the subject of various studies [8–11].

The craft sector has been affected disproportionately by the demographic change and will continue to do so: A large proportion of workers in this sector will retire in the next five to ten years. The general demographic of smaller cohorts following the so-called baby boomers won't be able to compensate for that. Furthermore, it can be observed that the choice of training by these overall fewer potential applicants, also in relative terms, was taken less and less in favour of craft professions [12]. At the same time, it is assumed that the demand for craft professionals will remain constant or even increase [13]. Thus, everything points to an increasing labour shortage in this sector. This calls for new technologies that could potentially increase labour productivity. Thus, those innovations need to emerge or be transferred and spread (diffuse) throughout the craft sector.

1.2 Innovation Diffusion

The fact that the craft sector does not use the potential of existing technologies to the same extent as the industrial sector raises the question of how innovations emerge in the craft sector. Innovation theory has produced various models to describe innovation processes. The traditional linear innovation model [14], which is based on a neo-classical understanding and thus often assumes an exogenous technology push, does not seem to be able to explain the different degrees of utilisation in industry and crafts: Technology and utilisation are open to both sectors. Considering individual perceptions and mutual influence between individuals and sectors seems to fit better to the focused craft sector. More current models from the group of systemic approaches, such as the *Technological Innovations Systems Approach*, for example, include those behavioural aspects [15].

Such behavioural aspects can arise, for example, from individual acceptance (or non-acceptance in case of rejection). Acceptance has been formalised through different models, whereas the *Technology Acceptance Model* (TAM) is the most commonly used. TAM has emerged less systematically than the aforementioned innovation theory models, but from requirements management for specific solutions [16]. Originally designed to assess the acceptance of information and communication technology, especially computer programs, various extensions (TAM2 and TAM3) have been established for a wide range of applications and have proven to be robust [17]. The TAM assumes that acceptance is directly related to the actual use of a certain technology [18], as it is depicted in Figure 1. In the context of basic innovation theory terminology, rooted in Schumpeter's work, this relates to what makes up an innovation in the first place: Namely, an invention or idea that becomes established by wide application [19]. The TAM makes it possible to interview probands before and after exposing them to novel technologies and to determine influencing factors and weightings through factor analysis.

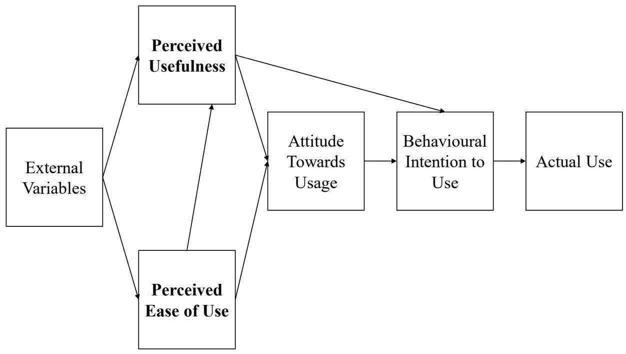

Figure 1. Modelled Technology Acceptance

1.3 Simulation in Production and Logistics

"A simulation is the imitation of the operation of a real-world process or system over time" which may be advised for a broad range of applications from operations research and systems analysis [20]. Simulation has been established for both planning new and replanning existing processes, systems, or factories in production and logistics. While a variety of different software suites has evolved to cover a wide area of application, the method of DES has become especially popular for many scopes of production and logistics. Bracht et al. classified visualisation as either to be dynamic or static to describe whether the visualisation is dynamically changing during the simulation run [21, 22]. Animation is a special type of visualisation, according to VDI 3633 Sheet 11 [23]. Nevertheless, animation is no synonym for simulation, which describes the method of computing a system's behaviour [22]. Wenzel points out that not only insights but also the communication of these insight ought to be achieved by simulation [24]. Common use cases are found in the automotive sector, commissioning, chemical industry, or food industry. It is striking that non-industrial production has not been examined with simulations, even though layout planning or scheduling is relevant in this sector as well. Recent developments have led to the establishment of 3D simulation, which is easily understood also by non-experts.

1.4 Virtual Reality

Digitisation and process optimisation projects are often accompanied by the expectation that the results will have a potentially positive impact on the profitability of value creation and are always associated with risks of failure due to project-inherent uncertainties [25].

Hence, early transparency is of great importance, which can be supported by VR. Figure 2 depicts the so-called reality-virtuality continuum, according to [26]: The most left pole represents the real environment, with no virtuality. The augmentation of real objects by context-based information is called augmented reality. The reason for that is, that real objects make up the majority of elements in the user's field of vision resp. perception [27]. Meanwhile, VR is usually created by displays that exclude real-world objects. Instead, a virtually created world is displayed and mostly synchronised to head movements to realistically stimulate human senses [28]. VR is not enabling a completely virtual environment, as humans, generally speaking, have other senses that are still connected to reality and not yet stimulated virtually, e.g. sense of balance, smelling, etc. Together, AR and VR make up the term *mixed reality* [29].

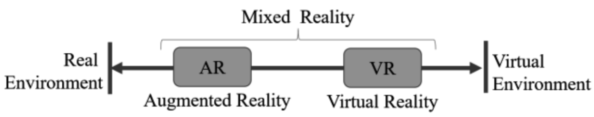

Figure 2. Reality-Virtuality Continuum according to [26]

According to the classification of Reif either head-mounted displays or emulators support the visualisation. For the proposed use case, the used HTC Vive counts as a head-mounted display, which is powered by an external computer, running the simulation [30]. The provided hardware allows six degrees of freedom, for best immersion: Three for rotative movements, usually of the head like yawing, rolling, and pitching, and the three translatory motion forward, leftward, or rightward [31].

VR applications can be already found in practice: Education, production planning, or process optimisation as well as the visualisation of products for customers are common applications [32]. One study found training, planning, and communication to be the most relevant topics for VR in crafts [33]. Figure 3 shows a welding simulation, which is one of the examples used in the aforementioned study. Furthermore, visualisation is stated for planning, even though the authors don't state layout planning explicitly for production environments but kitchen.

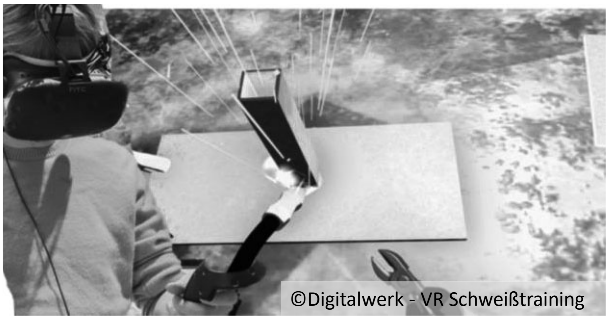

Figure 3. Welding Training in VR

VR offers a rather intuitive orientation and the possibility of a controlled environment that can be of high value, e.g. in training scenarios that are not feasible otherwise, as they might be too expensive or too dangerous. Potential drawbacks of such a technology is the so-called motion sickness [34].

2 Research Design

The research design employs use case analysis as it is common in engineering science to anecdotally pass on experiences of designing and implementing technical systems. That way, the lessons learned can be deduced and documented. The novelty of this topic strongly points towards explorative research. That is why, the proposed design integrates grounded theory from the field of social science. It is used to create hypotheses about human behaviour and social life from field data, which consists mainly of interview transcriptions and observations [35]. More precisely, abduction grounded theory is used, as theoretical elements from literature, as presented in section 1, are considered as well. The use case presents a convenient way to get in touch with the research object (craft professionals) and exposing them to DES and scheduling, which are state-of-the-art digital industrial methods. This *technology shock* is then used to track reactions from individuals and their associated groups, respective the company. The remainder of this paper discusses the identified use case and the planned data collection and analysis, while further aspects of the research design are displayed in section 4, once the use case has been described.

3 Use Case Description and Realisation

This section describes the activities planned to create a DES model and to display scheduling alternatives to craft professionals. Figure 4 represents the overall model of procedure. The main subtasks were adopted to a reduced extent from VDI 3633 [36]. The standard process (grey arrow) is deployed on an abstract level. This is to create modules of different layouts that may occur or make up actual workshops of craft companies. These modules were defined as flow shop or job shop layouts. Hence, modular simulation models for each of these two are implemented (blue arrow) using synthesised data, representing typical workshops of this sector. For the modelling of the actual workshop, the real-world data needs to replace the modules' dummy data, and parameters need to be set accordingly. Especially the 3D visualisation needs to reflect the specifics of the craft workshop. This can be done using 3D-design software such as Blender or CAD software like SolidWorks or Autodesk Inventor.

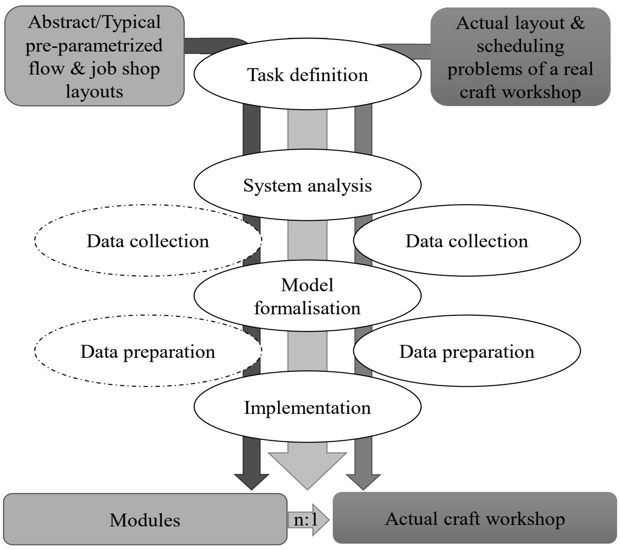

Figure 4. Model of Procedure for Simulation Creation

These 3D objects are then imported into the simulation software by Siemens Tecnomatix Plant Simulation. Only machines relevant for the schedule are designed in detail to ensure reasonable usage of resources. Other machinery or the workshop surrounding can be integrated as panes displaying 2D photos of the respective objects. This allows a shortcut in modelling while ensuring intuitive resemblance. Finally, a functioning virtual 3D image of the workshop is created (orange arrow).

3.1 Layout Patterns

This subsection presents the two main layout options that are thought to modular build up most craft workshops: Flow shop and job shop, which also determine the respective scheduling problems.

Flow Shop Problem (FSP) represents a scheduling problem where all jobs have the same processing sequence [37]. Usually, a flow shop is characterised by a flow-oriented layout, so that machines are arranged in series, as shown in Figure 5. This allows jobs to flow from an initial machine, through several intermediate machines to the final machine. This means that each operation after the first has exactly one direct predecessor, and each operation except the final machine has exactly one direct successor [38].

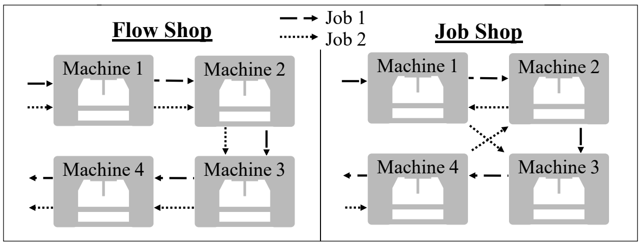

Figure 5. Flow Shop and Job Shop Layout Principles

Common objectives for FSPs are to find schedules that minimise longest completion time or makespan while maximising machine utilisation. This possibly leads to the highest throughput [39]. Flow shop production is usually associated with portfolios of only a few, highly standardised products, with predictable demand. Thus, the most common production strategy is *make-to-stock*. The number of constraints to consider, when scheduling, is significantly less than for a job shop layout. For instance, the setup time is rarely considered since setups do not occur often. A flow shop provides good visibility of occurring problems due to the linear layout.

Job Shop Problem (JSP) consists of jobs, running through a common production facility but having different machine orders [40]. Jilcha & Berhan [41] and Li et al. [42] present JSP using the following definition: Job shop scheduling happens in a work location of a given set of general-purpose workstations where a variety of jobs, each with a specific set of operations, is processed in a given sequence. Jobs, therefore, have their individual routing and might use all machines of the respective layout or a subset of these (see Figure 5).

A JSP's objective is usually to minimise the makespan, subject to the constraints specified for each job. Overall characteristics of production in a job shop environment can usually be summarised as follows: Firstly, the variety of products is very high due to the possibility of customisation. Therefore, the production layout requires high flexibility which leads to low process standardisation. Additionally, demand is harder to predict than for the typical FSP-associated product portfolio, since it usually operates under a make-to-order strategy. Admittedly, not only customised or single pieces are produced in job shop configuration, but small batches as well. Finally, regarding the workers' skills, professionals working in job shop layouts need to master more tasks, hence they require more training in their respective qualifications.

Scheduling production in a job shop environment should consider the following aspects: The make-to-order strategy is linked to the target of on-time delivery. Overlooking the process is much more complex since every product has its specific routing.

3.2 Priority Rule-based Scheduling

Priority rules have been used for decades as a scheduling procedure for production. Its main objective is to define the sequence in which the pending jobs are processed, in a given period. It is known that priority rules will usually provide less optimal solutions in comparison to what may be given by other advanced algorithms, e.g., genetic algorithms, neural networks, simulated annealing, etc. However, it is commonly used because its implementation is easy and does not require expert knowledge nor skills [43]. As more complex approaches may be feasible for some craft companies, the authors assess rule-based scheduling to be more suitable for most companies in the craft sector. Hence, scheduling shall be limited in this paper's scope to priority rules. The Encyclopedia of Production and Manufacturing Management [44], as well as Koruca & Aydemir [43], present in their work the most commonly used rules for production scheduling. Ten of these rules are introduced in Table 1 and will be implemented in the simulation modules.

Figure 6 depicts the implications from these rules, using 5 jobs (J1-J5) with varying process times.

Rule	Description
First come, First served (FCFS)	Jobs will be scheduled and processed according to which was first to arrive either in the queue or to the machine.
Last come, first served (LCFS)	The last job to arrive is the one that is scheduled or processed next.
Shortest processing time (SPT)	When scheduling the job, the one with the shortest processing time among those in the queue is processed next. This reduces the work in process inventory, the total flow time, and the average job lateness.
Longest processing time (LPT)	This rule will schedule the job with the longest processing time among the jobs in the queue, next. While using this rule for scheduling the total completion time or makespan will be minimised.
Earliest due date (EDD)	When applying this rule, the job with the earliest due date will be processed next. The main aim of the rule is to reduce job lateness.
Shortest remaining processing time (SRPT)	The job that will have the priority of being processed is the one that has the shortest remaining processing time. The main aim of this rule is to minimise the total completion time or makespan and minimise the latest job delivery time.
Longest remaining processing time (LRPT)	The job that has the longest remaining processing time will be processed next by the machine. The aim of this rule is to maximise the capacity utilisation of machines/workstations in the work location.
Slack time (ST)	Is a variant of earliest due date rule, considering the remaining processing time (setups and lead time). The job that has the smallest amount of slack gets top priority. This rule integrates customer orientation and capacity utilisation.
Next Queue (NQ)	While scheduling, the NQ rule considers the queues at each of the succeeding machines/workstations where the jobs are heading. The priority goes to the job whose machine/workstation has the smallest queue.

Table 1: Priority-based scheduling rules

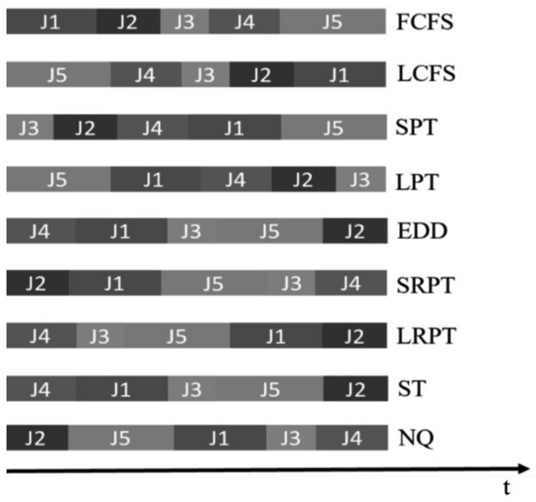

Figure 6. Priority-based scheduling rules, and their exemplary impact on the sequence of jobs

4 Further Course of the Study

According to the outlined research design, the use case of scheduling is embedded in the simulation and application of VR by craft professionals. The following subsections cover the methodological integration and the interviews.

4.1 Study and Use Case Integration

The use case analysis and the human factor analysis can be seen as two outcomes of this integrated work, which are different but not separate, as presented in Figure 7.

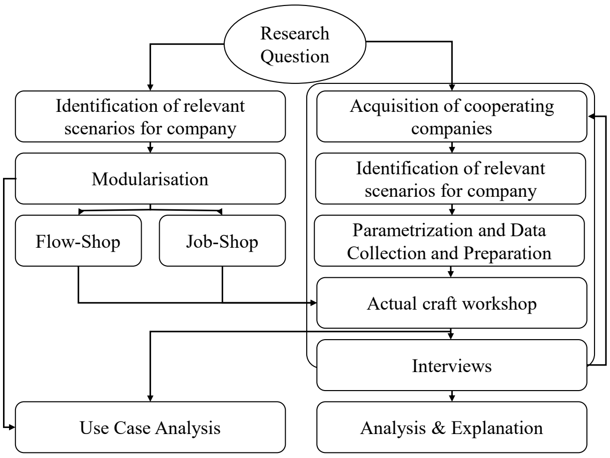

Figure 7. Model of Procedure for Conducting the Study

The work on the use case is currently ongoing as well as the acquisition of cooperating companies.
The research questions have been defined as:

- How is the innovation process characterised in the crafts sector? What roles do various individual and social stakeholders play?
- What kind of innovation-type classifications are feasible for craft companies?
- Which special features can promote the prevalence of novel technologies and how are they related?

The presented research design offers a path to find underpinning explanatory hypotheses for those research questions. The study that encloses the actual applications is designed and the data collection and analysis are prepared accordingly to the following subsection. A minimal feasible model has been created and software evaluated that allows realistic but also pragmatic modelling of the actual machinery. The adaption to the first actual workshop is the next step to be conducted.

4.2 Interview Preparation

Conversational interviews are the preferred interview technique for qualitative research at the exploratory stage [45]. Semi-structured guidance can promote story-telling by the interviewees. The target is to capture accounts of experience and behaviour related to the research question respectively leading to hypotheses. Thus, the theoretical background of section 1 was considered for the design of the guiding questions [46]. Nonetheless, the interviews should only be carefully guided, avoiding any priming of interviewees when it comes to attitudes and sentiments.

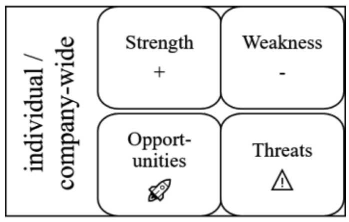

Figure 8. SWOT framework for Interview Guidance

Guidance can try to steer the conversation towards topics of internal or external communication, the used channels of communication and their recipients, usefulness, job relevance, ease of use, the perceived benefit and usage intention. For a similar approach, assessing a different use case the authors thought it useful to not reveal those subtopics directly nor the research question in order to achieve honest accounts. Therefore, the conversation was supported by a SWOT (Strength, Weakness, Opportunity and Weaknesses) template (Figure 8). This template is shortly explained to retain the interviewees' attention for the rest of the interview. This was assessed to cover the actual research questions well. Nevertheless, the interviewees ought to be made aware of the abstract topic of technology transfer into the craft sector for reasons of integrity. Provided the interviewees give their permission, the interviews are to be directly voice recorded or otherwise transcribed with great detail. Furthermore, impressions from the interview setting should be noted. This so-called corpus of qualitative data is then analysed by interpretation, identification, and assignment of patterns and the deduction of explanatory hypotheses.

5 Conclusion and Outlook

This paper presents a mixed-methods approach to exploratively study the acceptance and diffusion of innovations within the craft sector while realising a DES use case. A DES model of an actual craft workshop is intended to employ different scheduling scenarios, and show the effect on different performance indicators that are relevant across the sectors of industry and crafts. Scheduling, in this case, represents an industrial method that is demonstrated using digital technology, which is novel to the craft sector. Both, method and technology are not used extensively in crafts and, therefore, offer innovation potential. How craft professionals assess this potential and respective usage within their field of work on an individual but also a company-wide level is explored through accompanying conversational interviews.

This paper presents the outline of the research design and the underpinned model of procedure for the actual realisation of the use case. The study is currently at the phase of the use-case realisation and a minimal viable DES has been implemented. The authors hope to employ the proposed design on different occasions, receiving thick feedback data that can be documented and analysed, to formulate detailed hypotheses for technology acceptance and innovation diffusion in the craft sector.

Acknowledgements

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