Simulator-assisted lean production training
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ABSTRACT
In Lean Production training and education, simulators are often used. These can take the form of for instance desktop games, computer simulations, or full-scale simulators. Many training participants perceive models for experiential learning and for continuous improvement processes as complex and abstract. Based on experiences from training sessions in a full-scale simulator Karlstad Lean Factory®, a unified model for learning and improvement work is presented. This model stimulates training transfer and is perceived as intuitive. It also shows instructional scaffolding as a learning method. Suggestions for future work include investigating synergy with Smart Manufacturing and the use of Lean Production simulators for innovative product realisation.

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1. Introduction
Within the Lean Educators research community and amongst Lean Education practitioners, much attention is being paid to Training Within Industry (TWI) and to training for professional preparation of engineering students using simulated factory environments. This concept resembles what Herbert Schofield more than one century ago called an ‘instructional factory’ within the university. This was an approach that differed radically from the canned engineering education that was the prevailing teaching model at the time (Airey, 1921). Simulated factory environments used today for Lean Production (LP) education range from simple desktop games to actual manufacturing machinery such as so-called ‘Learning Factories’, the latter being described in Tisch et al. (2013). It depends amongst others on the target group(s) and the learning objectives which of these is to be preferred. Target groups can range from university students to industrial workers, with various levels of experience and with different prerequisites for learning and training (between groups but even within groups). With the adoption of Lean principles and tools in non-manufacturing sectors, target groups may be even more diverse, but this paper’s scope is mainly limited to manufacturing.

One important aspect of LP training is training transfer, i.e. how much of what has been learnt can be transferred to an actual or future work environment. Unfortunately, currently there are no commonly accepted models to describe training transfer and less so, commonly accepted methods to measure it. This is
somewhat symptomatic for LP education both as a research discipline and as a field of application; much of the literature on LP education is anecdotal, reporting on either incidental success stories or failed implementation of LP. One problem might be that LP training within industry is often delivered by consultants who – with some positive exceptions – tend to have limited interest or intention to share their experiences with the research community. This means that a potentially rich source for field data remains unused. Furthermore, the Authors’ experience is that training of industrial workers comes with some potential difficulties not encountered when educating university students. Some differences have been described in (De Vin & Jacobsson, 2017) and include differences in familiarity with formal instruction, and the fact that contact with university students usually is more frequent (which creates more opportunities to ‘guide’ them in the right direction if needed).

The aim of this work partially is to present a model describing the link between LP training and continuous improvement in the workplace in a way that supports both LP training participants and LP educators & trainers. Another aim is to report findings and experiences from using an LP simulator as a training tool. Apart from the Authors’ own experiences (as researchers immersed in a role as LP trainer/instructor), experiences reported in the literature as well as on focused platforms (such as ELEC – European Lean educators Conference) are included.

The disposition of the remainder of the paper is as follows. Firstly, different simulator types for LP training and education are described, without claiming to present and exhaustive overview. Next, models for learning and for continuous improvement are presented, resulting in a model that addresses both learning and improvement. Section 4 and 5 describe training experiences and research regarding the measurement of training effects. A summary of main findings is followed by an outlook and suggestions for future work both for LP education research in general and the simulator KLF Karlstad Lean Factory® in particular. For readers not familiar with previous publications on KLF, a description of this simulator is presented in Appendix A, which is a summary of Section 4 from (De Vin & Jacobsson, 2017).

2. Production simulation and its relevance to lean production training

Hands-on LP training using ‘Lean games’ is a form of simulation, and hence, it is useful to look at ‘Lean games’ from a modelling & simulation perspective as well as from an LP perspective.

2.1. Uses of simulation in production engineering

Lean Production training through various types of games can be seen as a form of simulation (De Vin, Jacobsson, & Odhe, 2018). In simulation, usually, a System of Interest (SoI) is studied (Brade, 2004). In some application fields, the expressions ‘Situation of Interest’ and ‘Scenario of Interest’ can also be used. Such an SoI may in manufacturing, for instance, be a workstation, a production line, or a factory. Generally speaking, simulation can be used for a wide range of purposes in Production Engineering including (De Vin, 2015):
Simulation as a tool to study an SoI in order to create new knowledge about the modelled system, or to refine existing knowledge about it. This new or improved knowledge can subsequently be used for decision support, often on operational level.

What-if analysis. A type of use that is similar to the above, but usually with a longer time horizon, and typically for tactical decisions. It can be used to study changes such as proposed layout changes of a production facility or introduction of new products.

Simulation as a tool to train operators in the use of the SoI. In this case, the simulation model serves as a means to transfer knowledge about the SoI to the operators. The SoI can be an existing system, an envisaged system, or a mix. In some cases, Virtual Reality (VR) or Augmented Reality (AR) tools are used. An example is an assembly worker learning to insert a physical tool or component into a virtually represented cramped space.

Simulation as a way to test and benchmark for instance production planning algorithms. Testing and comparing algorithms or other types of planning tools (such as soft computing) are not practically possible in a real production environment, but it is possible to do so in simulated environments.

Documentation and discussion. Through discussing commonalities and differences between the simulation model and the SoI, tacit knowledge about the SoI can be elicited. After completion of this process, the model can serve as a form of documentation of the functional behaviour of the SoI.

Serious gaming as a way to create situations that are realistic, even although the situation itself may never occur. Serious gaming is often used to train people and organisations for situations in which communication, coordination, and decision-making are important, such as in complicated rescue operations, terror threat mitigation, or natural disasters. In manufacturing engineering, it can be used to train aspects of LP and of general production planning.

What makes the latter purpose different from most of the other purposes is that there is less focus on a specific SoI and that the aim of the simulation not is to find an answer to a specific question. The aim of simulation in LP training and education is not to solve specific problems, but to equip the participants with transferable LP skills. Such skills are not just awareness about and experience of lean tools and principles, but they include changed attitudes and a culture of looking for improvement opportunities – an ‘LP mindset’.

Whilst the REVVA reference model for modelling & simulation (PROSPEC, 2002) is relevant to game-based LP training and education, one of the most important aspects of game-based LP training is training transfer from the training environment to the actual workplace or the envisaged future workplace (De Vin & Jacobsson, 2017; Luttik, 2017). However, one should not confuse LP skills with problem solving skills, as research by Hambach, Diezemann, Tisch, and Metternich (2016) revealed no significant correlation between LP performance and problem solving skills. Whilst problem-solving skills as such generally are important for continuous improvement on shop floor level, LP as such is more multi-faceted. For instance, on shop floor level, holistic production flow thinking and the ability to identify improvement potential are also important. Thinking
in a holistic manner implies the ability ‘to see the greater picture’ whereas seeking to identify improvement potential is an attitude. The degree of inclusion of all employees is also important. The instructor/trainer plays an important role in highlighting these aspects of LP. Individual participants’ skills alone may not be a sufficiently good measure for group performance as a whole.

2.2. Types of lean production simulators for training and education

In the previous work (De Vin et al., 2018), the authors have argued that it is important to match the simulator with the participant groups and the purpose of the training. For different participant groups and/or different purposes, different simulators and game scenarios are appropriate. Miller (1954) suggests that training transfer increases with increased similarity between the simulator and the ‘real’ equipment. On the other hand, Johansson (2012) points out that simulators that are too advanced and complicated can confuse novices, and Wood, Bruner, and Ross (1976) indicate that a simplification of the task is essential in order to give regulated feedback regarding critical features of a task. In computer simulation, for instance, it is considered to be an art and a skill to build models that have exactly the right level of detail for their purpose. They shall be neither too simple nor too detailed (‘just enough detail to do the job’). Without claiming that the overview below is exhaustive, the following main types of popular LP simulators can be distinguished:

- Paper-based games
- Desktop games
- Full-scale (or near full-scale) simulators
- Teaching factories
- Computer simulation

*Paper-based games* are often used as shorter exercises to elucidate one or a few aspect(s) of LP. They are relatively inexpensive and an additional advantage is that participants can play game rounds even without the presence of an instructor/trainer; in some cases, these can even be played by a single participant. An example is a game where variations in demand and in production capacity are simulated with the use of dice. By playing several rounds, the effects of variations on throughput and other performance indicators can be simulated for various scenarios, for instance as in (Roser, 2017). For some of these games, a computer-based score sheet (e.g. in Excel) is available. A disadvantage can be that some games are perceived as fairly abstract; for instance, the use of dice to simulate variability in demand and/or in processes is not always well understood by all participants.

*Desktop games* are usually based on the assembly of for instance LEGO® or similar products such as the ‘Muscle Car’ simulator (Pourabdollahian, Taisch, & Kerga, 2012). These games are popular not in the least due to their portability and the fact that they do not require specific facilities. However, even these games tend to be fairly abstract, and it is an advantage if game participants are used to working with abstractions and analogies. Unfortunately, many university students lack exposure to industrial manufacturing environments and this can make it difficult for them to see the analogies.
Desktop games can be used to teach some basic concepts, but for experienced workers, the games lack sufficient realism (Dukovska-Popovska, Hove-Madsen, & Nielsen, 2008). Another disadvantage is that change efforts are not always realistic (Van Laere, Lindblom, & Susi, 2007). This can result in improvement suggestions that would not be realistic in a real work environment.

*Full-scale and near full-scale simulators* usually contain ‘workstations’ that are almost full-size. Examples of such simulators are pedal car assembly lines and wheelbarrow assembly lines. A disadvantage of many of these simulators is that they typically focus on assembly. The product components tend to be bulky, which is a limitation when transporting them. For this reason, most of these simulators are used at a fixed location. KLF fits into this category but is more mobile and simulates both material processing and assembly. It is described in more detail in De Vin and Jacobsson (2017) and in Appendix A.

*Teaching Factories* (also called ‘Mini-Factory’ or ‘Learning Factory’) usually consists of real manufacturing machinery. They are very similar to a real industrial environment and usually consist of high-end manufacturing machinery. A potential disadvantage is that they are relatively inflexible and very specific for a certain type of production (Tisch et al., 2013), and their high level of detail may render them less suitable for novices. Due to their nature, the majority of these simulators are stationary. Due to the level of detail, there is a certain risk for equipment specific improvement suggestions from the participants. They are usually suitable for training experienced machine operators, which highlights the importance of matching the simulator with the participant group.

*Computer simulation* has the advantage that participants can ‘experiment’ with various parameters such as cycle times, availability etcetera. This means that many different solutions can be tested in a relatively short time. However, layout changes typically require programming skills. The Authors sometimes use computer simulation as a complement to full-scale simulators to demonstrate some basic concepts when training university students. For instance, once the students are familiar with a simulator (in this case Karlstad Lean Factory®), a computer simulation can be used to demonstrate the effects of for instance shorter cycle times, increased equipment availability, a higher number of transport trucks, or different workload.

Some authors suggest to link VR/AR tools to production simulation software in order to create higher degrees of participant immersion (Abidi, Lyonnet, Chevaillier, & Toscano, 2016; Gamlin, Breedon, & Medjdoub, 2014). However, despite the fact that VR/AR tools have been available during several decades and that they have become increasingly affordable, the use of them for LP training purposes is up to date relatively uncommon. This may be due to the fact that the purpose of LP training usually is not to solve a particular problem for a particular production facility, but to train participants in LP tools & principles, and to stimulate an open LP culture. Hence, in many cases, the role for VR/AR in basic LP training might be fairly limited, despite it being an exciting technology. Nevertheless, VR/AR has large potential for assisting LP training and alignment when it is impractical to physically co-locate different actors in an organisation (or across a supply network). This type of AR/VR use may require a certain minimum level of LP proficiency.
Aures (2017) describes a rather unique simulation game used at AUDI AG that does not quite fit into one of the categories mentioned above (closest match probably is the category ‘near full-scale simulators’). This game is a simulation of a sandwich bar that sells sandwiches configured according to customers’ orders. The game has been designed with great care in order to contain game scenario elements that are similar to some main features of production of mass-customised cars. Thus, it fulfils two characteristics that according to Aures are important for a suitable LP game: The game must be far away enough from the real work environment to be a game, but close enough for training transfer. Seemingly, the game is a low fidelity simulator (to use the terminology from Miller (1954)), but actually it has surprisingly large similarities to the real work environment. The game stimulates creativity although this also means that some solutions can be unexpected and unconventional, which can be a challenge for the trainer/instructor.

3. Lean production training for continuous improvement

Below, first some models for experiential learning in general are presented.

3.1. Models for experiential learning

Game-based LP training is usually part of a process called ‘experiential learning’ (Kolb, 1984). It means that the participants experiment using a game and then experience the effects of their actions. If the game is too easy, the participants tend to lose interest whereas if the game or task is too difficult, they get frustrated.

One of the pitfalls for LP education practitioners is that what may look like a rather simple game to the trainer actually may be experienced as complex and abstract by some participants. For instance, a popular way to simulate variation in table-top games or paper-based games is the use of dice to simulate variability. Many LP trainers and consultants use such games (ELEC, 2017; Elias, 2016; Roser, 2017). However, it is the Authors’ experience that not all participants, industrial workers and university students alike, grasp the concept that dice are used to simulate variations in demand and variations in production capacity. This was most notoriously illustrated by a post-training comment from an industrial participant ‘What was this with the dice about? Our customers don’t use dice when they place an order.’ Questions from engineering students also indicate that they do not always understand that dice are a way to simulate variability, in particular regarding variations in production capacity.

Many models for simulation-based gaming & learning might be useful to study interaction and learning processes as a research topic, but do not support LP training practitioners in their work. These models, such as the Lemniscate model by Koops and Hoevenaar (2012), are usually too complex to support game scenario design and they are definitely too complex to explain the improvement and learning process to LP training participants.

3.2. Models for continuous improvement

A model frequently used to describe improvement processes is the PDCA cycle (Plan-Do-Check-Act), often attributed to W. Edwards Deming. However, various interpretations of
this cycle exist. Furthermore, students and LP training participants often experience the model as abstract and awkward to use. This view is supported by Moen (2009) who claims that Deming disliked PDCA as the latter considered it suitable for very simple improvements only. Reportedly, Deming instead suggested to use PDSA (with ‘S’ for Study) as a model for improvement and learning as a further development from the Shewhart Cycle presented in Deming (1986). Sometimes, the PDCA model is presented as a cascade of improvement loops so as to suggest continuous improvement (Figure 1).

One of the problems related to the PDCA loop is that many different interpretations and modifications exist. With the ‘original’ (or what is popularly thought to be the original) standing for Plan-Do-Check-Act, some replace ‘Act’ with ‘Adjust’, and others replace ‘Check’ with ‘Study’. The latter modification reportedly is also Deming’s preferred interpretation as it suggests a learning step (Moen, 2009). The PDCA/PDSA loop is used to describe anything from small improvement steps in the workplace to strategic decision-making on business level. This need not be a problem as such, but it means that the descriptions of the steps and activities within each phase can differ significantly, depending on the organisational level and the type of the improvement process at hand. This often leads to confusion, even amongst professionals (Radziwill, 2011). Thus, despite its popularity, this model may not be the best choice when explaining improvement processes to LP novices.

3.3. KLF model for experiential learning and continuous improvement

Below, a model that was initially proposed by the authors in (De Vin & Jacobsson, 2017) and which has been refined further is shown in Figure 2. It consists of two parts. The left part pertains to simulator-assisted learning, and the right part to the work situation. A training session starts with an initial instruction session (not shown in the model), after which the participants play a simulation round followed by a debriefing session for feedback. Then, after a peer discussion (of which individual self-reflection is a component), a change decision is made, followed by a new game round. The instructor/trainer is predominantly present inside the learning cycle. The variant to the right reflects improvement in the work situation and is rather similar. This facilitates training transfer; in essence, the participants implement the same way of working and thinking in their daily work. This will result in organic learning and the role of the instructor becomes more that of an external observer.

![Figure 1. PDCA loop as stand-alone loop and as cascade of iterations.](image)
As mentioned, models for learning can become quite complex and abstract, and the PDCA cycle (or PDSA cycle) can be perceived as abstract as well. The Authors believe that by using one model with only minor variations for describing both training activities and improvement processes, the model more clearly links the improvement and learning process in the training environment to improvement and learning in the work environment and that thus, training transfer can be increased through increased awareness of the similarities. As an example, after one training session with a small company, a group of blue-collar workers suggested to make an opening in a wall to reduce transports and to improve communication between departments. Asked by company management how they arrived at that idea they responded: ‘We started to look at the factory in the same way we looked at KLF during the training’.

Another advantage of the model above is that it also shows a process called ‘instructional scaffolding’, a term first introduced by Wood et al. (1976). A KLF training session typically starts with an introduction including game instructions to make sure that participants have a common view of the task and a common vocabulary (particularly important when training employees from different companies in one group). During the training, they receive feedback mainly from the instructor but sometimes also from more experienced peers. LP training is not only ‘learning by doing’ but also ‘doing from learning’ as the instructor gradually explains more LP concepts. This provides a ‘scaffolding’ that allows the participants to reach a level of proficiency that they would not be able to reach on their own. At their workplace, this scaffolding is gradually removed as the coach or facilitator moves to the background more and more while the participants individually and as a group make progress through their proximate zone of development.

The trained eye may recognise the PDCA loop (or rather: PDSA loop) in the model above, but one important difference is that the model proposed by the Authors is of descriptive nature rather than being prescriptive. The PDCA model is often used in a prescriptive way with checklists of what to do in each step. Training participants often experience a descriptive model as less formal and more intuitive.
4. Training experiences from karlstad Lean Factory® (KLF)

Almost inevitably, an account of training experiences contributes to the relatively large collection of anecdotal evidence. However, such accounts can be helpful to understand the complexity of LP training.

The Authors have extensive experience from LP training and education of industrial workers and university students. They have used desktop games as well as the full-scale simulator KLF. They themselves have participated in various LP training sessions using various simulators.

One major difference between using desktop games versus full-scale simulators is that participants who have no active role stay much more engaged when full-scale simulators are used, regardless of the participant group (although the impression exists that in particular industrial white-collar workers have a tendency to lose attention when desktop games are used). Furthermore, layout changes are discussed more intensively when using full-scale simulators, as layout changes in desktop games usually are relatively effortless which causes participants to suggest changes that would be unrealistic in reality. A similar effect has been noted by Van Laere et al. (2007).

Regardless of the participant group, eventually the games tend to develop towards similar solutions. This also happens when a game is played by only one team (they arrive at a similar solution as other teams playing the same game scenario), which means that it is not the result of two teams copying each other’s solutions (improvement steps). In literature, it is sometimes suggested to play with at least two teams in order to create a competitive aspect (Dukovska-Popovska et al., 2008), but the Authors are of the opinion that competition between teams is not necessarily positive. Competition often results in teams ‘working too hard’ thus, in essence, creating a non-sustainable work environment. Also, teams tend to compare scores (a performance measure) after each round and sometimes try to improve their score by reducing WIP towards the end of a round. In particular university students and white-collar workers are prone to do that (instead of explaining that in essence, they are losing production capacity, the instructor can also announce ‘5 minutes overtime’ which usually is quite an eye-opener). However, playing with multiple teams from one company has the advantage that they can compare their alternative improvement strategies after the training. They also experience that there is no single ‘best solution’ and that different improvement routes can lead to similar results.

In particular when training university students or white-collar workers, the combination of KLF and computer simulation often works well. As an example, the Authors have been using a simple line with four workstations whereof two have limited availability (average service times and intervals MTTR and MTBF can be pre-set on the KLF workstations). A computer simulation allows evaluating many different scenarios (w.r.t. availability, variability, and cycle times) in a short time. However, for those unfamiliar with production flow simulation, this can become quite abstract. When one exposes participants to a physical production simulation in KLF first, then they can relate to the KLF simulation when they look at the computer simulation. For instance, when a workstation is blocked or a buffer is full in the computer animation, they can relate this to the ‘frustration’ they experienced in KLF when a machine was down for service or blocked by a full buffer. Figure 3 shows a partial screenshot of a simulated line with knock-on effects from a broken down station.
Assessment of training effects

The importance of adequate LP training and education is widely acknowledged. For instance, Marodin and Saurin (2015) mention the lack of effective training as a barrier for LP implementation and as amplifying other barriers, and Sanders, Elangeswaran, & Wulfsberg (2016) identify improper training and performance evaluation as major barriers for LP implementation. One important aspect of LP training is how much is transferred to the work environment. This is called ‘training transfer’ and is described in Luttik (2017) as ‘That almost magical link between classroom performance and something which is supposed to happen in real world’. Unfortunately, measurement of training transfer is not trivial. Even the measurement of the effects of LP education on university students is difficult enough. Students are used to various examination forms, which facilitates measurement as such, but still there often is no clear correlation between exam results and skills acquired (Hambach et al., 2016). For industrial workers, in particular blue-collar workers, traditional examination forms are even less suitable. When training transfer is measured indirectly through production improvements, it is difficult to identify the contribution of LP training to such improvements. Other factors including the Hawthorne effect may play a role in such improvements. This means that the measurement of training transfer remains a research gap for this moment. An overview of measurement methods and tools to assess training transfer presented in De Zan, De Toni, Fornasier, and Battistella (2015) reveals a wide variety of assessment criteria proposed by various authors, but remarkably enough, ‘inclusion’ does not appear in any set. Chiva, Alegre, and Lapiedra (2007) present a simpler assessment method more suitable for SMEs, but even in their list of criteria, inclusion is absent. Inclusion means the degree to which minorities (e.g. gender minorities or ethnic minorities) are given equal say during group discussions. Inclusion is important not only to reduce what is often called the 8th waste (unutilised human creativity) but also for a better work morale in general. Bicheno (2017) mentions inclusion and downplaying of status as one of the major factors for the success of the WWII Bletchley code breakers team. The instructor/trainer has a particular responsibility to make sure that all participants have equal say during a training session.
6. Conclusion

Simulator-assisted Lean Production training has been identified as a form of simulation called 'serious gaming'. A number of different simulator types have been presented, with a focus on full-scale simulators. It can be beneficial to combine different types of simulations. Lean Production training can be seen both as a learning process and as a continuous improvement process. The Authors have presented a novel model that stimulates training transfer and that also illustrates instructional scaffolding. Measurement of Lean production training effects on organisations and on individuals has been identified as an area with both a research gap and a gap in industrial practice.

7. Outlook and future work

Good LP education and training is important as LP is often seen as an excellent base to build Smart Manufacturing (Industry 4.0) upon (Buer, Strandhagen, and Chan (2018)). This is not surprising as there is a parallel with the automation migration strategy from the 80s called 'USA' standing for 'Understand – Simplify – Automate'. An important aspect of LP is to understand the production environment, to identify value-adding and non-value-adding activities, and to make the production environment well-structured and transparent, thereby eliminating unnecessary complexity.

One issue related to LP is that it is difficult enough to measure an organisation’s LP maturity in itself, let alone to identify the contribution of LP training and education to LP competence and maturity. With this respect, there is both a research gap and a gap in industrial practice. At the same time, there are probably also vast amounts of field data that could be unlocked.

It is often suggested that organisations with higher LP maturity are more prone to be innovative. In a forthcoming project, the Authors intend to extend the use of Karlstad Lean Factory® from being just a training environment to an environment where companies, SMEs in particular, can test innovative production solutions or production solutions for innovative products.

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Appendix A: KLF Karlstad Lean Factory® equipment

A.1 Design considerations for the lab

Simple paper-based games or LEGO® based games are suitable to teach some basic concepts of Lean Production (LP), but for training experienced industrial workers, such games usually lack sufficient realism. They differ too much from the participants’ work context. Full-scale simulators such as push car or wheelbarrow ‘factories’ focus on assembly. However, most manufacturing sites contain both assembly and materials processing (for instance milling, turning, sheet metal processing). Initiated by discussions with a.o. local industry, the concept of KLF was developed. The aim was to build a lab that would be more realistically representing a manufacturing environment whilst at the same time being flexible enough to simulate various work environments. One initial idea was to represent a working machine by a rotating disk. This would work fine for milling and turning, but it could be a distracting detail for many other processes. Hence, this idea got abandoned. Apart from designing the workstations, candidate products had to be considered as well. The main functional requirements (R) and desirable features (D) included:

- Ability to simulate a manufacturing line as a whole (R)
- Ability to simulate a variety of processing stations in a realistic manner (R):
  - Should have ‘fixtures’ to simulate changeovers (R)
  - Possibility to simulate Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR) (R)
  - Not limited to one single type of product (D)
- Ability to simulate non-manufacturing processes (D)
- Mobility to enable on-site training (R)

It should be noted that the requirements pertain to discrete processing, i.e. an item (or group of items) is subjected to a process with a discrete start time and a discrete completion time. The resulting concept is presented below.

A.2 KLF Equipment

Karlstad Lean Factory has been developed and built completely in house. Currently, the lab has three types of work stations (Figure A1):

- Materials processing stations for processing of single components
- Batch processing stations
- Assembly areas

The first two types of stations are equipped with stack lights and twin (two-hand operated) start buttons. They also have an electronic unit on which the processing time as well as MTBF

Figure A1. From left to right: KLF Single component processing station, batch processing station, and assembly area.
and MTTR can be set by the instructor on a simple setup panel. The latter have a uniform distribution between 50% and 150% of the set value. This means for instance that if MTBF is set so as to generate on average four stoppages during a simulation run, at least two will occur, but never more than six. This is a way to simulate variability whilst controlling the number of disturbances so as to avoid extreme situations (which may occur in reality but which are not very useful for training purposes). The single component processing machines are equipped with a pallet for fixtures. All stations are easy to move for mobility (on-site training) and for facilitating layout changes during a training session. The detailed design of the work stations and the choice of the current product (a children’s chair) will not be discussed here, but there are several subtle options to work with SMED and/or standardisation of the product. However, a limitation of working with physical equipment such as this is that suggestions for Poka-Yoke solutions not always can be implemented ‘on the spot’ during the course of a training session. However, such suggestions demonstrate the participants’ engagement.

The product currently used for simulations is an IKEA children’s chair (also shown in Figure A1). The assembly is easy to learn within just a few assembly cycles, which means that improvements between simulation runs are not influenced by increased proficiency of the participants regarding the assembly task itself. A relatively easy assembly task was deemed suitable as the simulations as such are a mix of materials processing and assembly; hence assembly is only a small part and its main purpose in the simulation is to make any upstream problems visible. The chairs had to be modified as the original chairs are not designed for frequent assembly and disassembly. By using chairs with different colours, batch production and mixed-model production can be simulated if desired. Other simulation options include special customer orders (e.g. white chair with black seat) and ‘make or buy’ decisions.