Karlstad lean factory: an instructional factory for game-based lean manufacturing training

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ABSTRACT
Simulation for training lean manufacturing ranges from simple paper-based or LEGO®-based games to larger scale simulation environments, for instance push car assembly. Some models for game-based learning are discussed and a model for lean manufacturing training is adopted. Many types of simulation may be suitable for teaching some basic elements of Lean manufacturing to students, but they are often less suitable for training industry workers in applying Lean manufacturing in their work environment. The latter group is more used to intuitive learning than to formal instruction. Thus, it is important that a training environment for this group more realistically represents the work environment; otherwise training transfer will be limited. For this reason, a lean training environment that includes materials processing stations as well as assembly areas was created. The stations exhibit some realistic behaviour such as stochastic breakdowns. Based on a comparison between factory workers and university students, five hypotheses for testing in future work are proposed.

1. Introduction

Many lean games for training of factory workers in lean manufacturing are a form of serious gaming, which in turn is often seen as a form of simulation (Cannon, 1995; Crookall, 2010; De Vin, 2015; Greitzer, Kuchar, & Huston, 2007; Van Laere, Lindblom, & Susi, 2007). For better understanding lean games, the role and nature of models and simulations in general will be discussed first. The REVVA reference model for computer simulation (PROSPEC, 2002) will be adapted to represent simulation-based training.

In literature on serious gaming theory, there tends to be relatively much attention for educating university students and training military personnel. Literature on game-based training of factory workers or healthcare workers is usually of more applied nature, for instance describing specific cases. There also appears to be relatively much attention for computer-based games rather than for more realistic physical training environments, even within manufacturing education (Mavrikios, Papakostas, Mourtzis, & Chryssoulouris, 2013). Some models for learning through serious gaming will be discussed, and a model that is
suitable to represent both learning lean manufacturing through serious games and learning in the workplace will be adopted.

Despite the usefulness of paper- and computer-based games, game-based training of factory workers requires a more realistic training environment. This motivated the design and building of ‘Karlstad Lean Factory’ which is a training environment that realistically emulates a manufacturing environment with a combination of materials processing and assembly. As such, it is an example of an ‘instructional factory’ to use the expression coined by Herbert Schofield during WWI (Airey, 1921).

2. Models, simulation, and serious gaming

An important notion in simulation is the so-called System of Interest (SoI) which is the system under investigation. Depending on the discipline and type of simulation, SoI can also stand for ‘Situation of Interest’ or ‘Scenario of Interest.’ The relationship between the SoI and its associated model is shown in Figure 1. The model is an abstract representation of the SoI and ideally, from the behaviour of the model, conclusions can be drawn concerning the SoI. Likewise, from the observed behaviour of the SoI, conclusions can be drawn concerning the model, such as its suitability to represent the SoI. A model can never be identical to its associated SoI, because if it would be, then there would probably be no need for a model in the first place. Or, as Rosenblueth and Wiener (1945) put it:

No substantial part of the universe is so simple that it can be grasped and controlled without abstraction. Abstraction consists in replacing the part of the universe under consideration by a model of similar but simpler structure. Models [... ] are thus a central necessity of scientific procedure.

The validity of a model, which is one of the measures for its suitability, depends on the intended purpose (Brade, 2004; De Vin, 2015; PROSPEC, 2002). An important and obvious consequence of this is that a model that is valid and suitable for one purpose can be totally unsuitable for another purpose. An example of incorrect use of a model is extending its use outside the model’s validated window, which unfortunately is not uncommon.

Figure 1 above can be adapted to explain the role of the simulation game context in game-based learning and training. The simulation game context represents to some degree the real world context (for instance, the work environment). The purpose of the training (‘the game’) usually is that the participants acquire knowledge and skills that they subsequently

Figure 1. System of Interest (SoI) and model (PROSPEC, 2002).
use in their work situation. This defines the learning objectives. Many lean games consist of a number of rounds in which participants try and evaluate various improvements. This process of experimenting and experiencing is often called ‘experiential learning.’ The result from this process, the learning outcomes, can be compared with the learning objectives through debriefing, guided group discussions and so on. This is also a way to avoid negative training (learning ‘incorrect’ actions through for instance discrepancies between work environment and training environment). An example of negative training is a group of students who grasp what the ‘score’ (a measure for how well the team performed) at the end of a game round is based on and then slow down production towards the end of the round to reduce Work in Process (WIP) – but in essence, they lose production capacity in doing so.

For industrial participants, an important aspect is the degree to which the learning outcomes are useful in the work environment. Such useful outcomes can be tangible outcomes, like specific skills, but also ‘soft’ outcomes such as increased appetite to learn new things and a new way to look at the own work environment. Specific skills can for instance be proficiency to operate a certain type of machine or proficiency to carry out an assembly task, understanding of some basic lean manufacturing tools, or understanding of production planning and control methods. However, achieving the ‘soft’ goals such as creating an attitude change and a new culture is at least equally important for most companies. It is reasonable to assume that the learning outcomes will be different for different participant groups. Thus, the validity of a lean game does not only depend on its purpose but also on its participants. This is illustrated by Figure 2 (Jacobsson, Wickberg, & De Vin, 2016). Figure 2 shows a static representation of relationships only. It should be noted that learning itself is a continuous and often cyclic process (with experiential learning, debriefing, peer discussion, and self-reflection as important elements) as described in Section 3 below.

For some simulators, the expression ‘fidelity’ is used as a measure of similarity between the training equipment and the ‘real’ equipment. However, this expression usually pertains to single station equipment (e.g. an aircraft cockpit) whereas a simulation environment for manufacturing consists of multiple stations. Furthermore, such an environment can be used in different ways in different production scenarios. Hence, the expression ‘context similarity’ is preferred in this paper most of the time.

Figure 2. Simulation-based learning.
3. Serious gaming and lean manufacturing training

3.1. General observations from literature

Pourabdollahian, Taisch, and Kerga (2012) indicate that serious gaming for manufacturing education and training is a relatively novel area. They identify several reasons why serious gaming is a good way to educate industrial workers. These include the possibility for participants to assume various roles, and the possibility to take complex collaborative decisions without interfering with production. They also emphasise the importance of a realistic game context to allow participants to immerse themselves in the simulation environment.

Messaadia et al. (2013) report that a job-like training environment is important. Their paper describes assembly of a LEGO®-size product called ‘Muscle Car’. They suggest performing training sessions first, and discussing theory afterwards. As one of the main benefits they report awareness about and interest for Lean manufacturing. They conclude that serious gaming is ‘a relevant delivery mechanism to learn lean principles and to improve attitude, knowledge, skills and competencies about lean manufacturing’.

In general, literature and lean manufacturing consultants report a number of benefits from serious gaming such as more engagement and better understanding of lean principles in complex settings. Mostafa, Dumrak, and Soltan (2013) mention that adequate lean manufacturing education and training can reduce the resistance towards lean transformation that may exist amongst factory workers. However, Thomas et al. (2016) suggest that innovation in Welsh SMEs may indirectly even have been hindered by a too simplistic level of lean manufacturing training.

Table-top (often paper-based) exercises tend to draw the participants’ attention away from the problems and instead make them focus on the effects of their game actions whilst underestimating the effort required for these actions (Van Laere et al., 2007). On the other hand, games that are too complex can have the effect that participants attribute success to ‘luck’ or ‘hard work’ instead of seeing the correlation between their actions and the results (Cannon, 1995).

3.2. Models for learning through serious gaming

Kolb (1984) mentions the existence of a so-called flow channel in game-based learning. If the task is too difficult for the participant, the participant gets frustrated or feels anxiety. If the task is too trivial or simple, the participant gets bored. In between, there is a zone in which the participant is engaged in the task. In more recent work (Kolb & Kolb, 2009; Koops & Hoevenaar, 2012), this zone is divided into two zones. One zone is called the gaming zone (or comfort zone) and the other zone is the learning zone (or challenge zone), see Figure 3. Learning takes place by zig-zagging between these two zones. This process of zig-zagging is often represented as switching between a gaming cycle and a learning cycle, as shown in Figure 4 (redrawn from Koops & Hoevenaar, 2012). The learning cycle was presented by Csikszentmihályi (1975) whereas the gaming cycle is rather similar to Boyd’s cycle (observe, orient, decide, act) which witnesses of its military pedigree.

Garris, Ahlers, and Driskell (2002) propose a model for game-based learning that describes learning as input-process-output (Figure 5). With ‘User Behavior’ not just the technical interaction of the user with the (computer) game is meant, but also responses to
the game as a whole, such as user attitude and engagement. Hence, ‘user behavior’ is seen to represent a variety of different responses to the game (or task).
Although probably no single model can fully grasp the complexity of learning (in line with our discussion of ‘models’ in Section 2), this model seems to have some important limitations when it comes to its suitability to represent Lean manufacturing games:

- Different participants may, at least initially, exhibit different responses. Hence, ‘user characteristics’ should be part of the input.
- The model does not represent any changes in the instructional content. Typically, these will change between different game iterations as the user’s level of proficiency and level of understanding increases.
- The model does not incorporate how the user changes the game characteristics, which is typical for lean manufacturing training: One of the user’s tasks actually is to change the game characteristics through suggesting, implementing and testing improvements.
- The model does not show interaction with other players or a trainer which again is important for lean manufacturing where debriefing and peer discussion are important activities.

In order to address these issues, the authors of this paper adopted the model for game-based lean manufacturing training shown in Figure 6. The model includes debriefing and peer discussion, which are absent from the model in Figure 5. In the adopted model, learning is a cyclic process and the game cycle is a loop within this cycle. Important activities are debriefing, self-reflection, and peer discussion which usually is guided by a trainer/facilitator. Debriefing is important not only to highlight the main results from the game round(s), but also to avoid any negative training. Moreover, debriefing usually helps the participants to formulate their own observations during peer discussion (thus transferring tacit knowledge into explicit knowledge). An important task of the trainer/facilitator during the discussion phase is to ensure that all participants get equal opportunity to participate actively and to ventilate their ideas. Thus, the model indirectly also stresses the need of training the instructor; whilst proficiency in lean manufacturing is an obvious prerequisite, other skills are needed as well. The reflection and discussion phase is followed by a change decision which is implemented in the next game cycle. The nature and content of debriefing may vary as the participants’ proficiency increases. Typically, an instructor or facilitator acts as moderator during the learning cycle. Their role during the game cycle usually is that of observer and interaction is limited to factual input such as clarification of the instructions. The model can also describe learning and continuous improvement in the workplace when

![Figure 6. Proposed model for lean manufacturing training using Karlstad Lean Factory.](image-url)
the game cycle is replaced by the work cycle. In that case, debriefing can be led by an external facilitator or by an internal lean coordinator, and can also take the form of pulse meetings.

### 3.3. Factory workers as participant group

We have observed that groups such as factory workers or personnel in healthcare can exhibit relative diversity. For instance, when we compare factory workers with university students, then some characteristic differences (as observed from own experience or mentioned in literature) can be:

- Factory workers are more used to learning-by-doing, or implicit learning, whereas university students are much more used to formal instruction and guided learning.
- Partly as a result from this, the knowledge of factory workers usually is tacit knowledge. This as opposed to knowledge that students possess, which often is more explicit knowledge.
- Factory workers usually have more difficulty to transfer knowledge from one domain to another. University students are more used to working with analogies and their knowledge usually is more portable, even if analogies sometimes have to be explained to them first (Dukovska-Popovska, Hove-Madsen, & Nielsen, 2008).
- Factory workers can exhibit a wider range of motivation for participation and learning; some may just attend ‘because ordered to do so’ whereas others may see it as an opportunity for professional development and improvement of their workplace.
- Factory workers usually have a wider need for debriefing, guidance and group-reflection. For instance, to avoid negative training.

It should be noted that the list above is not meant to generalize, but rather it should be seen as some of the reasons why factory workers generally are a more diverse group than the relatively homogeneous group of university students. An exception could occur when one compares workers in one department of one local factory with students from an international Masters course (which typically exhibit a range of cultural and other backgrounds). Regarding motivation for instance, some workers may attend a course just ‘because my boss sent me’ whereas others see it as an opportunity to develop personally, to improve their work environment, and to contribute to a secure future for the factory. The latter group has a very strong motivation that probably few students would be able to match.

An important aspect of training workers is that the task must be sufficiently meaningful and not too trivial. When training health care workers for instance, the task must not be too simple (Gaba, 2004) and work by Thorvald, Bäckstrand, Högberg, and Case (2012) indicates a similar effect for assembly workers. Miller (1954) has studied the effects of similarity between training equipment and real equipment. He found that while costs rise steeply for high-fidelity simulators, the training transfer curve flattens out (Figure 7).

The implication of the above is that a good simulation gaming environment for factory workers would need to provide sufficient context (fidelity) and enable meaningful training scenarios without being too specific. This was part of the motivation for building the Karlstad Lean Factory.
4. Karlstad lean factory

4.1. Design considerations for the lab

As Dukovska-Popovska et al. (2008) mention, simple simulations (paper based games or LEGO® based games) are suitable to teach some basic concepts of Lean manufacturing to inexperienced participants. This is why they can be used to teach some Lean basics to university students. However, for experienced workers, such games lack sufficient realism. They differ too much from the participants’ work context.

For this reason, larger scale labs for training Lean have emerged. Examples in Scandinavia include labs based on push car or wheel barrow assembly (such as those in Trollhättan, Skövde, Gävle, and KTH Stockholm), and mini-house assembly (Gjøvik). However, most manufacturing sites contain both assembly and materials processing (for instance milling, turning, sheet metal processing). Training labs based solely on assembly have some disadvantages in this respect. Firstly, participants may have a tendency to focus on improving small parts of the assembly process rather than focusing on the overall situation. Secondly, due to the absence of processing units, the effects of disturbances and of different equipment maintenance strategies are difficult to emulate. Thirdly, the possibility to simulate layout changes is usually limited to some basic assembly line balancing suggestions. Furthermore, assembly processes may not always be suitable to represent non-manufacturing activities such as health care processes. Finally, some of these labs have relatively bulky products and work stations. This does not facilitate mobility and on-site training.

Considering the above, the idea to build a lab that would be more realistically representing a manufacturing environment whilst at the same time being flexible enough to simulate other work environments emerged. For instance, one idea was to represent a process by a rotating disk which would work fine for milling and turning, but which could be a distracting detail for other processes. Hence, this idea was abandoned. Apart from designing the

![Image of effect of fidelity on training transfer.](Figure 7. Effect of fidelity on training transfer.)
workstations, candidate products had to be considered as well. Some of the 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.

4.2. Karlstad lean factory equipment

Karlstad Lean Factory has been developed and built completely in house. Currently, the lab has three types of work stations (Figure 8):

- 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 and MTTR can be set by the instructor (Figure 9). 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

Figure 8. From left to right: Single component processing station, batch processing station, and assembly area.
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 standardization of the product. Figure 10 shows a close-up of a machine’s work area with setup instructions for the operators. However, a limitation of working with

Figure 9. Instructor’s setup panel.

Figure 10. Close-up of machines during a simulation.
physical equipment such as this is that suggestions for Poka-Yoke solutions cannot always be implemented ‘on the spot’ during the course of a training session.

The product currently used for simulations is an IKEA children's chair (also shown in Figure 8). 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 different colours, batch production and mixed-model production can be simulated if desired.

4.3. Some notes on training scenarios

Currently, the lab is being evaluated using relatively standard training scenarios, such as starting with a layout in which the work stations are not co-located and spread out fairly randomly (Figure 11). Some chair components were modified in such a way that assembly was not possible. Typically, this is not noticed until final assembly and creates discussion on for instance supplier reliability, the ‘right from me’ principle, and design for assembly. The batch processing stations can represent for instance heat treatment or surface coating processes. There is a variety of rules that the instructor can set initially, such as only processing a batch of identical components (where rules may vary, e.g. ‘always 6’, ‘maximum of 8’, and so on) or always processing all components for one final assembly (similar to kitting). The batch stations could also represent a CNC punch-press processing a number of identical components nested in a sheet, or a sheet containing dissimilar components (which could improve single-item flow downstream). These examples of different ‘rules’ show that the lab

Figure 11. Example of starting layout for a simulation session.
can be tailored easily so as to emulate different manufacturing environments. In addition to the possibilities above, the workstations allow simulation of a variety of product mixes; from processing one product type in one variant via one product type in multiple variants to multiple product types in multiple variants.

Karlstad Lean Factory also facilitates including the supply network perspective not only through various component supply models but also because it is relatively easy to include non-conforming items. There are also possibilities to simulate kitting and assembly line balancing. For instance, a rule for the batch processing stations could be to process all internal components of a product which are subsequently assembled in 2–3 stations (possibly with in-sequence delivery of external components). This type of option means that Karlstad Lean Factory can be used not only to train factory floor workers but also to train white collar workers including management. It also demonstrates the possibilities to deliver realistic company-tailored training scenarios.

The layout shown in Figure 11 is a typical layout when training novices in the field of lean manufacturing. It incorporates unnecessary transports, and unnecessary batch processing on one station. When training more experienced workers, the starting point of the game would be different and more rules/principles included, such as pull systems (which in itself may be constant demand to start with and fluctuating demand in more complex scenarios), multiple product variants, or special orders. Thus, as the learning objectives become more advanced, the game scenarios tend to become more complex in order to meet these demands. Likewise, Greitzer et al. (2007) propose a layered training concept for cybersecurity games where scenarios become more difficult and complex as the participants’ proficiency increases.

Dukovska-Popovska et al. (2008) stress the importance of in-between reflections and after-game reflections. Initial findings are that this becomes even more important when training industry workers. Debriefing has several purposes, such as (i) to guide the participants, (ii) to give positive feedback and to stimulate experimentation and learning, (iii) to help participants to formulate their own observations and thus turning tacit knowledge into explicit knowledge, and (iv) to avoid negative training. Although learning outcomes have a prominent position in the reference model presented in Figure 2, learning should be defined as a process and not in terms of learning objectives (Kolb & Kolb, 2009). The main purpose of Karlstad Lean Factory is to create a learning, self-developing workforce and not to teach some specific practices or methods, even if these can be important in their own right.

4.4. Simulation of non-manufacturing activities

Since the work stations are relatively generic, the use of Karlstad Lean Factory is not restricted to just manufacturing. The ‘workstations’ can—at least in principle—represent any discrete process (i.e. a process with a start time and a completion time). For instance, the pallets with fixtures can easily be replaced by other equipment. Another example is the use of stack lights and the possibility to set MTBF and MTTR. With a relatively short MTBF and a long MTTR (as compared to manufacturing), a red light could represent an Intensive Care (IC) patient needing immediate attention. However, despite interest from health care organisations and educators, such extended use is not what Karlstad Lean Factory has been designed for. Nevertheless, it might still be suitable to teach some lean principles and in
some cases better so than table-top games. It can also serve as inspiration for other labs to be developed for non-manufacturing sectors and serve as a testbed regarding functionality.

5. Future work

Future work on Karlstad Lean Factory will mainly consist of two parts: (i) further development of the lab and of gaming methodology for the lab, and (ii) using the lab to contribute to serious gaming theory linked to training of manufacturing professionals. The latter will require collaboration with other serious gaming researchers and practitioners. For instance, Allert and Säfsten (2014) have found that the effects of improvement initiatives vary significantly between companies, even if one only considers small to medium sized manufacturing companies in a single country. This variability of effects means that forming a holistic picture most likely is beyond the capabilities of a single research group. This is also in line with Crookall (2010) who suggests research collaboration to develop simulation/gaming as a discipline.

Figure 12 shows five hypotheses described below that can be tested in future work, with ‘0’ denoting the original S-curve for training transfer according to Miller (1954) as previously shown in Figure 7. Whilst at least some of these hypotheses will be addressed in future research, it can be expected that they already now can provide support to lean education practitioners as they define a number of areas of particular interest when training industrial workers. In conjunction with this, methods for measuring absorption of education may also need to be assessed in order to establish how well they can measure absorption of training by industrial workers. There are some examples where absorption is tested through a written exam or a self-reflection report but these may not be the best tools for measuring absorption of lean manufacturing training amongst shop floor workers. Allert and Säfsten (2014) have also identified objective measurement of absorption and training effects as a potential issue. However, measurement of absorption and effects is beyond the scope of our current paper which is why it has not been discussed in more detail.

The five hypotheses suggested are (numbers correspond with the numbers in Figure 12):

![Figure 12](image.png)

*Figure 12. Training transfer for different participant groups according to the five hypotheses.*
(1) Factory workers generally are a much more diverse group than university students. Hence, instead of a single line representing a training transfer curve, there presumably is a wider band.

(2) In the low- to medium fidelity range, factory workers probably need more similarity between the work environment and the training environment for the same amount of training transfer as university students. Or, likewise, the training transfer will differ for the same degree of similarity.

(3) In particular (as a special case of ‘2’ above), factory workers require a higher degree of similarity for training transfer to take place at all. There already is some anecdotal evidence supporting this, for instance some industry workers have difficulties understanding the use of dices to simulate variability (as is often done in table-top games to simulate variable demand or production capacity).

(4) For simulation environments with a high degree of similarity to the work environment, the training transfer for factory workers probably surpasses that for university students, as participants from the former group have concrete work experience that they can relate to.

(5) For novices in manufacturing (including university students), high fidelity simulators are not very suitable. This is because too sophisticated simulators require the participants to understand the various parts of the functionality before they can attain understanding of the system as a whole. This hypothesis is already partly supported by Maran and Glavin (2003) and by Johansson (2012).

Addressing all the hypotheses above probably is beyond the capabilities and resources of a single research group. Some of the hypotheses can be tested and possibly refined in parallel with training industry workers and students in Karlstad Lean Factory. Karlstad Lean Factory is not primarily meant as a research facility and although studying the effects of too complex simulation environments on novices could be interesting from a scientific point of view, this is not what Karlstad Lean Factory will be used for in the foreseeable future. However, Hypotheses 5 may be of interest for the simulation/gaming research society at large. Responses from lean education practitioners (e.g. during ELEC2015) suggest that the hypotheses shown in Figure 12 and described above are useful when designing or selecting lean manufacturing games for specific participant groups.

6. Conclusions

A simulation environment for training industrial workers in lean manufacturing has been presented. The lab aims to be a complement to simple lean games and to assembly-focused labs. It consists of stations that realistically emulate an industrial environment for discrete manufacturing. It is highly adaptable and is also capable to emulate some non-manufacturing environments containing discrete processes. A reference model for simulation-based learning that highlights the importance of the participant group has been presented (Figure 2), and a model that describes learning lean manufacturing as a cyclic process has been adopted (Figure 6). A discussion of relative diversity of industrial workers has resulted in the formulation of a number of hypotheses to be tested in future work. Even prior to future testing, these hypotheses can already now support lean education practitioners. In
conjunction with testing the hypotheses, methods to assess training absorption and its effects may need to be reviewed.

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