von Heyl, J., 2015. Lean Simulation in Road Construction: Teaching of basic Lean Principles. In: *Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction*. Perth. Australia, pp. 403-412, available at www.iglc.net

LEAN SIMULATION IN ROAD CONSTRUCTION: TEACHING OF BASIC LEAN PRINCIPALS

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ABSTRACT

Since the first adaption of lean management to the building sector, numerous principals, methods and tools have been successfully adapted, developed and implemented and the term Lean Construction has been coined. However, Lean Construction is often only partially or incorrectly applied. A basic cause is that site management and workers are not familiar with Lean Construction, therefore only reluctantly applying lean methods and tools. But successful application of Lean Construction requires a holistic and determined approach with convinced project participants. Thus a systematic approach to teach basic lean principals and tools is crucial for the acceptance and application of Lean Construction.

In this paper a developed simulation game is depicted. A road construction site and its logistics are simulated. In the round based game a logistic chain and the operating grade of a finishing machine are getting optimized. First the traditional planning and execution of the site with its limitations and characteristics are simulated. Afterwards the participants discuss possible improvements. Then the site is simulated once more, this time using lean principles and an active management of bottlenecks. The gained improvements in productivity are examined by the participants and the lessons learnt are described.

KEYWORDS

Lean construction, action learning, logistics, kanban, flow, collaboration.

INTRODUCTION

Many construction companies suffer from inefficiency and operational problems at their construction sites. Approaches like Lean Construction are increasingly applied in order to improve the productivity and thus the profit margin. In Germany Lean Construction has been successfully implemented in many projects but it proves to be a continuing challenge to secure the improvements made and to qualify staff.

A road construction site is highly dependent on a steady supply of material. The application of lean principles can help to decrease the work flow variability in order to improve efficiency (Tommelein, Riley and Howell, 1999). Several road

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construction projects in Germany have been improved successfully using lean principles (e.g. L611 Bauschlott, B466 Neresheim or A8 Hohberg – Enztal (Mayer, 2009)). In order to apply lean principles the use of simulations can be beneficial to optimize planning and production processes. Particularly the logistics can be examined well with simulations in order to improve reliability and efficiency of manufacturing processes (Berner et al., 2013).

An important aim of road construction companies applying lean construction is the dissemination and the transfer of lean principles and lessons learnt to their work staff (Mayer, 2009). Simulation games are seen as an important supplemental tool for teaching leans principles and methods (Choomlucksana, 2013). This paper describes a simulation game developed on the basis of the lessons learnt from several optimization projects dealing with supply chains at road construction sites. Sticking points are central planning and management as well as implementing a continuous flow through cycle times and kanban cards.

LEAN MANAGEMENT IN ROAD CONSTRUCTION

OPERATIONAL CHALLENGES

Construction sites still offer a significant potential for improvements. A very promising working point for the improvement of many road construction sites or earthworks is the logistics (Gehbauer, Koskela and Kirchbach, 2014).

At road construction sites the supply chain between the mixing plant and the finisher is often unreliable and inefficient. Traffic, insufficient planning, inexperienced drivers and untuned processes disturb the continuous flow and lead to pack forming of the trucks. An integral logistics planning often doesn't take place. Furthermore it is quite common that the tasks within the logistics management are indefinite. At many road construction sites possible bottlenecks are not consequently identified and eliminated in advance, so rescheduling is required during construction. At the same time insufficient planning of the internal and external resources takes place. As a consequence construction managers have to deal with unreliable schedules, insufficient supply and troubleshooting. That all causes mistakes and a waste of resources (muda). The trucks, the mixing plant and the finisher are often not used up to their potential. An analysis showed that the trucks were standing idle in average 50% of their cycle time (Kaiser and Zikas, 2009).

OPTIMIZATION APPROACHES

The following optimization measures were carried out at several road construction sites. The finisher was identified as the most important factor in the production process. Therefore all processes were aligned to the finisher in order to enable an uninterrupted production. At first the production capacity of the finisher was identified, after that the required resources (type and quantity) were determined. The steady supply of the construction site is crucial for an uninterrupted construction activity. A formula was developed to determine the required amount of trucks at a road construction site.

$$\text{Amount of trucks} = \frac{P \times T \times S}{C}$$

Performance finisher = P [t/sec]
Circulation time = T [sec]
Capacity of truck = C [t/truck]
Safety factor = S [-]

Figure 1: Formula to determine required amount of trucks

The required amount is calculated based on the performance of the finisher. The capacity of the trucks and the safety factor are empirical values. The cycle time of the truck has to be determined in trials for each project. The definition of a sequence of the trucks stabilizes the supply chain. The routes of the trucks are planned and managed centrally. So are the delivery, breaking and tanking times of each truck. A cycle time was defined aligned to the capacity of the finisher. This made it possible to establish a continuous flow. Kanban cards were introduced to ensure that the truck drivers complied with the specifications (routes, times and standards). Due to the measures described above, the supply chain could be stabilized. As can be seen from the figure 2, a stable and steady supply of the finisher was realized.

A less interrupted delivery of material reduced the waiting times of the finisher and trucks and the output of the finisher went up from 182 t/h to 302 t/h. Thus an improvement of the performance by approximately 66% was realized (Kaiser and Zikas, 2009).

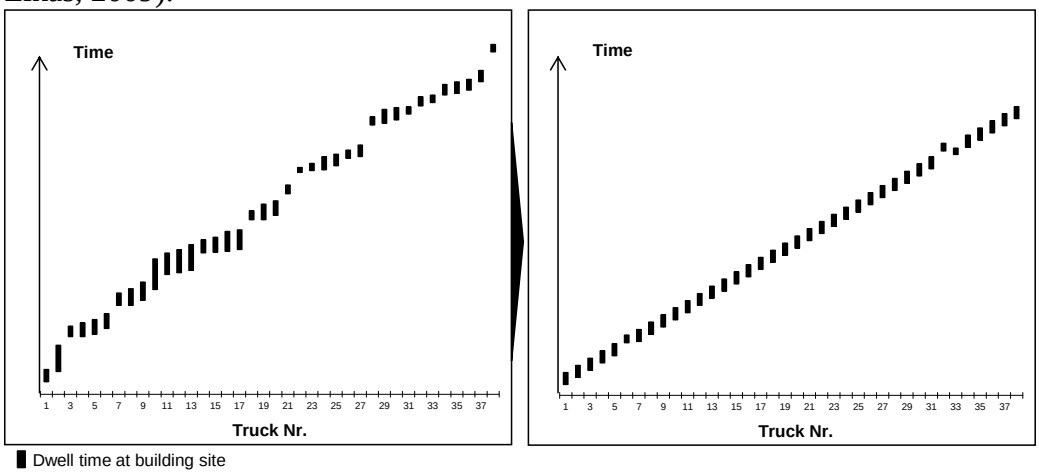

Figure 2: Stable supply chain after implementing cycle time and continuous flow

SIMULATION GAME

BACKGROUND ON TEACHING / SIMULATION GAMES

Teaching Lean Construction is not trivial as abstract concepts as well as specific approaches and terms have to be taught. Therefore a professional approach is required (Pellicer and Ponz-Tienda, 2014). The probability of memorizing information increases with the number of temporal, spatial and semantic relationships that are developed between the contents. Furthermore emotions and existing knowledge have a great influence (Donovan, 2007). The most promising teaching methods encourage learners to independently practice and reflect contents. A connection with the professional and personal situation of learners can accelerate the learning process significantly (Bransford, Brown and Cocking, 2003). Consequently, action and person-oriented teaching is desirable to impart action competence. Action competence refers to the ability to deal independently with situations. Situations are characterized by the accumulation of obstacles that hamper goal fulfillment. These obstacles should be tackled while the overall solution is taken into account. The action competence can be further distinguished by hierarchy as shown in figure 3 (Ott, 2000).

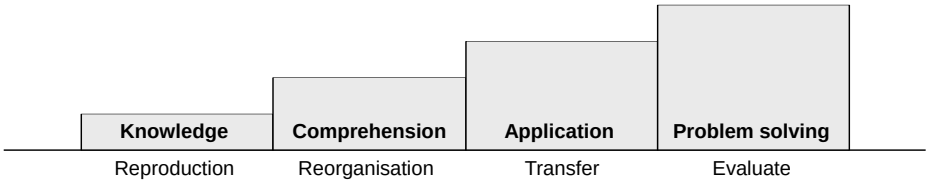

Figure 3: Hierarchy of action competence according to Ott

Simulation games are an appropriate method to improve action competence as they simplify a complex real world problem to its essential structure in order to teach techniques, skills and competences. Based on the game, the student is introduced to a topic or problem and is asked to independently find an approach to the problem. This promotes his autonomy and decision-making skills. The participants are involved very actively and encouraged to practice and reflect the contents taught. The simulation game in this paper addresses professionals and focuses on self-directed and autonomous learning. To teach Lean Construction using simulation games is not a new approach. Several games have already been successfully developed to impart lean principles (e.g. LEBSCO (González et al., 2015), LEAPCON (Sacks, 2007) or the Lean Hospital Game (Dukovska-Popovska, Hove-Madsen and Nielsen, 2008)).

ADDRESSED CHARACTERISTICS / DEPICTED CONTENTS

As shown before the logistics are a very important factor of a road construction site - a functioning supply chain contributes to more reliability and more efficiency. It is intended to simulate a traditional road construction site and its supply chain with its typical framework and challenges.

Table 1: Simulated Framework and Challenges of road construction sites

Framework	Challenges
Long supply routes	Pack forming of trucks
Limited buffer size at mixing plant and road construction site	Tendency to individual optimization instead of integral optimization
Material requires a minimum temperature	Mutual obstruction of trucks
Restricted working and driving times	Lack of coordination (breaks, routes etc.)
Required preparatory work and rework	Machine failure
Machinery supply and maintenance	Challenges maneuvering the trucks
Limited production capacity of finisher and mixing plant	Changing traffic density

Subsequently the participants have to optimize the supply chain between a mixing plant and a finisher similarly to the optimization approaches depicted above. Central planning and management is introduced in order to increase the output and to optimize the use of resources.

GAMEPLAY

Like other simulation games (e.g. LEBSCO (González et al., 2015)) the game consists of two rounds. First a traditional road construction site with its typical framework and challenges is simulated. In the second round optimizations are

introduced, with certain aspects of the game being pre-set. Thus the sequence of the game is the following:

- Step 1: Introduction and explanation of basic lean principles.
- Step 2: 1st round.
- Step 3: Analysis and discussion.
- Step 4: 2nd round.
- *Step 5: Analysis*, discussion and feedback.

Before the simulation can be carried out, the various roles of the game (e.g. truck driver, mixing plant worker, construction site worker) are assigned to the participants. Subsequently, the principles and rules of the simulation are explained. It is crucial that all participants understand their individual role and tasks. To ensure that all rules and tasks were correctly received and understood, test runs are recommended before the first round of simulation is carried out.

After completion of the first round subjective impressions are queried and discussed. KPIs are identified and the construction process gets evaluated, using provided forms. Now possible improvements are worked out in groups. The Game master complements the suggestions and proposes an optimization procedure inspired by the optimization approaches described above. Subsequently the participants calculate the required amount of trucks and implement the process improvements in order to eliminate waiting times and to optimize the use of resources. Now the second round gets carried out. Possible improvements that have been worked out at step 3 are taken into account. Reducing the amount of trucks and establishing a continuous flow with kanban cards out improves the reliability of supply. Hence the transport cycles are shorter, resources are used in a more efficient way and fewer batches are damaged. The figure 4 exemplifies the realized reduction of waiting time.

Afterwards the second round gets evaluated. Again the participants are working in groups to think of further possible improvements. Each group presents their ideas and tries to apply the learnt principles to the construction sites that they are currently dealing with. Finally the participants give their feedback on the simulation game.

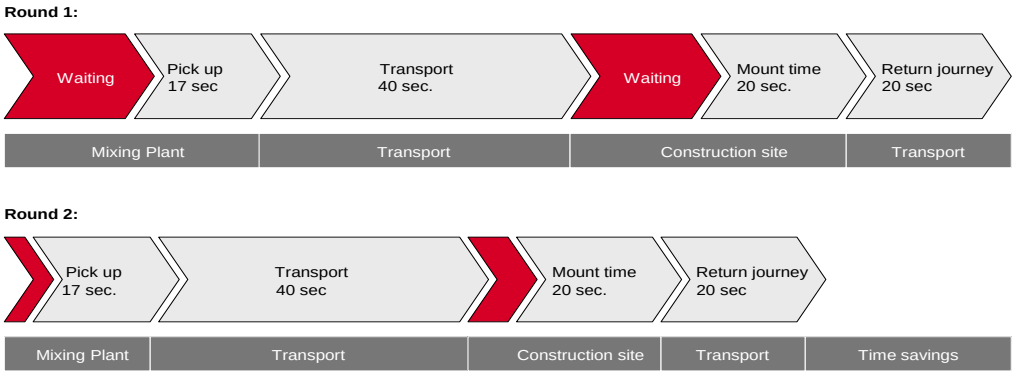

Figure 4: Shorter transport cycles in round 2

GAME ROLES

The game has different roles with specific tasks and purposes as listed in the table below. Each game participant receives a role. At least 12 players are required for the different roles and tasks.

Table 2: Game roles

Role	Pers.	Task / Purpose
Truck driver	8	Remote control of trucks; transport and unload of asphalt batches
Mixing plant	2	Operation of marble run and silo; measuring downtimes; responsible for delivery notes (log up and handing over)
Site worker	1	Acceptance of asphalt batches and delivery notes; responsible for asphalt paving; documentation of delivery notes; sort out defective material; measuring downtimes
Observer	>0	Observing the gameplay; documentation of interesting incidents; ensuring compliance with rules of the game
Game Master	1	Introduction and explanation of roles, rules, gameplay and game elements; ensuring compliance with rules of the game; play of gameplay cards; moderation and control

GAME ELEMENTS

The following elements of the supply chain are simulated: means of transport, mixture, mixing plant, construction site with finisher, resting area and the possible routes. In addition, a central timer, stopwatches, several cards (gameplay and kanban) and form sheets are necessary.

The asphalt batches (mixture) are symbolized by 50 wood cuboids – a cuboid fits into a miniature truck. If transportation time exceeds 120 seconds the asphalt batches are considered to be too cold and therefore are declared as damaged goods. Asphalt batches are delivered with a delivery note. This note also contains information that needs to be registered by the participants.

A central timer shows the current time of the game. In addition the participants that are responsible for the mixing plant or the construction site get a stopwatch to measure downtime (muda). Eight remote-controlled and numbered miniature trucks are used as means of transport. The mixing plant is simulated with a marble run and a slide. The throughput time of the marble run symbolizes the required time for a mixing process. The slide can hold four asphalt batches and symbolizes the silos (buffer). After the marble ran through the marble run, an asphalt batch can be put on the slide. Only if the slide contains less than four batches the mixing process can be executed. The trucks pick up the batches from the slide as illustrated in the figure 6.

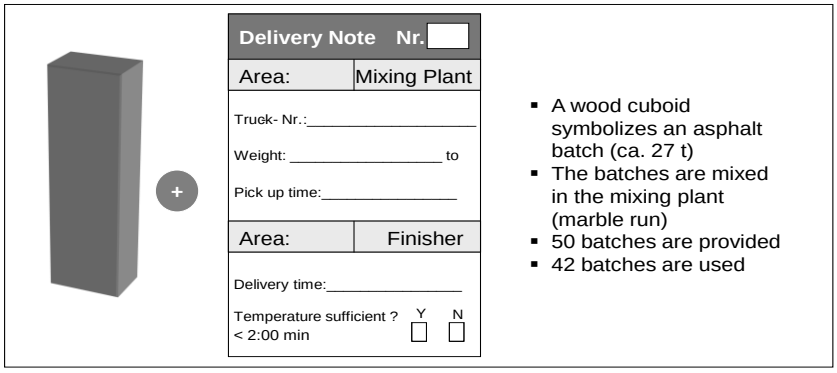

Figure 5: Wood cuboids and delivery notes

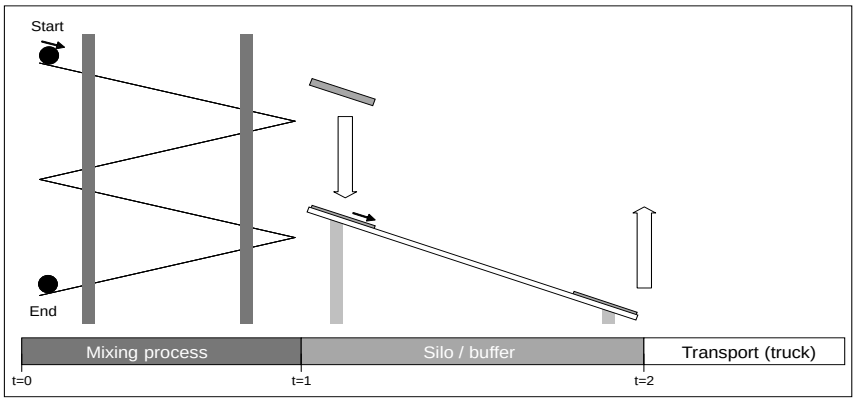

Figure 6: Mixing plant

The construction site and the finisher are symbolized by a wooden track with markings to show the construction progress. In addition, areas for the delivery notes and damaged asphalt batches as well as a delivery zone for the trucks are indicated. Once the truck arrives, the asphalt batch and the delivery note are accepted if the delivery time doesn't exceed 120 seconds. If the delivery time exceeds 120 seconds, the batch is declared as damaged good and can't be used anymore. The successive deposition of the asphalt batches on the wooden track simulates the construction process.

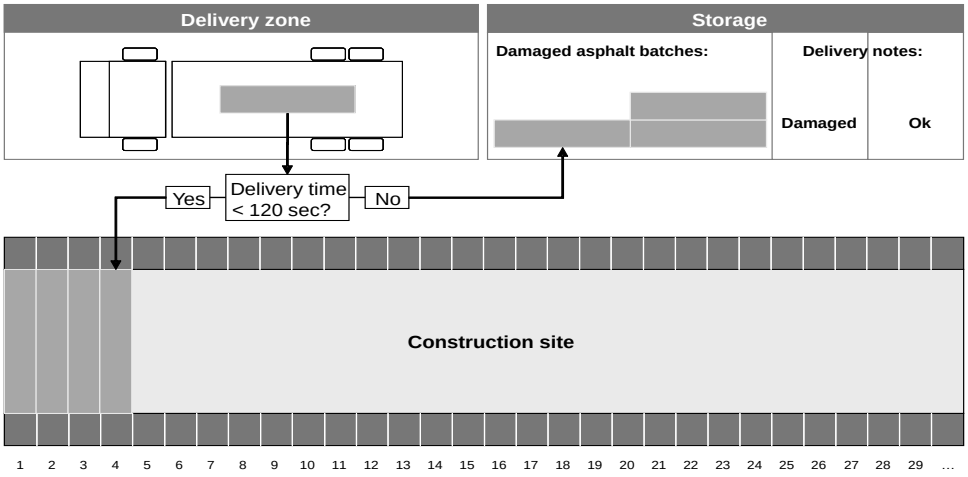

Figure 7: Construction site

The participants can follow different courses, which are staked out with small gateways. The gateways have to be passed in a certain sequence. The course is

divided into four routes: Three routes of different length from the mixing plant to the construction site and one from the construction site to the mixing plant.

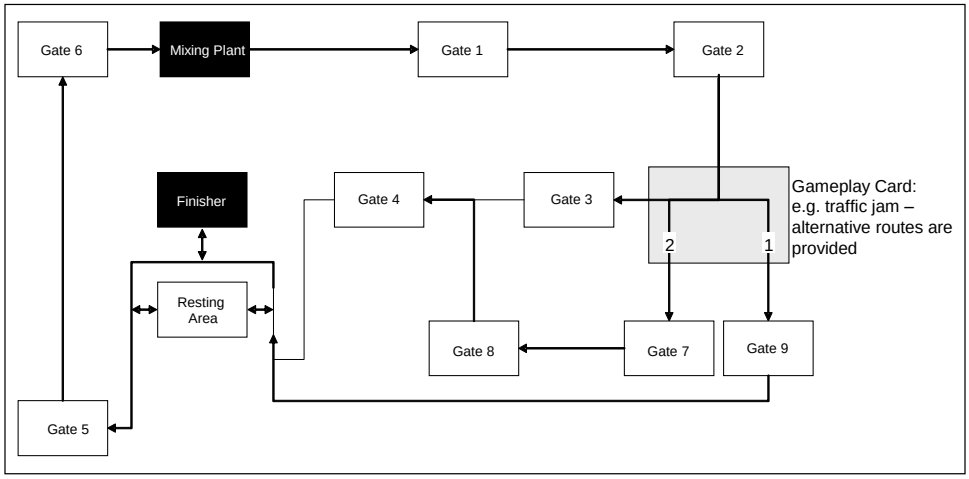

Figure 8: Course between the mixing plant and the construction site

The resting and refuelling of the trucks has to be done in the resting area. Each truck-driver has to rest at least once for 90 seconds – the resting times are registered. To simulate the refuelling process a form needs to be filled out – the required time symbolizes the time spent at the gas station. During the game certain events, e.g. traffic jam or police controls are simulated (gameplay cards). At first the routes are freely selectable whereas in the second round the shortest route or an alternative route in case of traffic jams or police controls is set. Like that the positive effects of a systematic route planning and global optimization can be demonstrated.

At the beginning of the second round the required amount of trucks is calculated. The resource allocation is optimized and kanban cards are now introduced in order to define a specific rhythm for each truck.

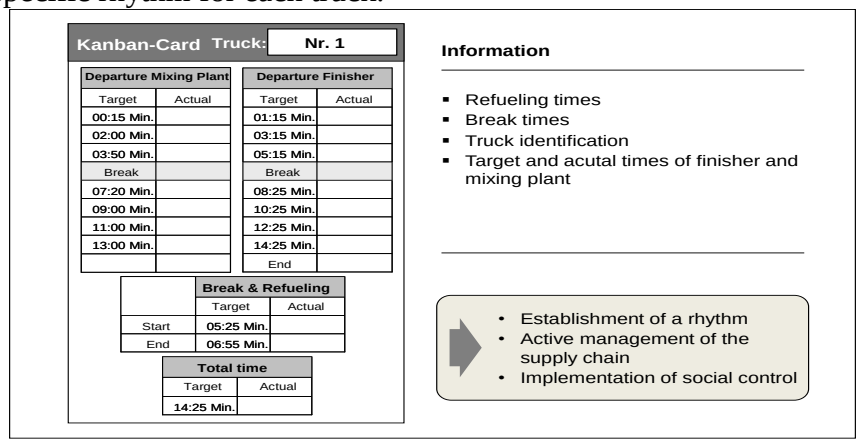

Figure 9: Kanban-Cards

The times when the batch is picked up and delivered as well as the breaking and refuelling points are pre-set. In order to detect deviations the actual times of the trucks have to be registered in the kanban cards.

Very important for the learning effect is that the use of resources and important process times are documented after each round. At the end of the simulation the figures can be compared and improvements are made visible.

EVALUATION

The game got tested in a test run with interns at a consulting company in Germany. The assessment of the participants was queried and data got collected. The test run showed that the basic framework and challenges of a road construction site were simulated successfully. The connections made with the personal situation and knowledge of the participants facilitates the learning process. It was possible to involve the participants actively with all sensory channels. The play-like character and the practical relevance of the training helped to motivate the participants. They got encouraged to give lean principles a try and to excogitate about existing processes and possible improvements. In the following table the KPIs of both rounds are compared.

Table 3: KPIs of the trial run

KPI	1st Round	2nd Round	Difference
Trucks	8	6	-25%
Waiting time mixing plant	~ 180 sec	~ 60 sec	-66%
Waiting time construction site	0 sec	~ 20 sec	+100%
Built in asphalt batches	30	42	+40%
Damaged asphalt batches	15	0	-100%
Scrap	33,3%	0%	-100%

The improvements made from the 1st to the 2nd round demonstrate the potentials of Lean Construction. The apparent improvement is expected to inspire the participants to try Lean Construction at their own construction site.

CONCLUSIONS

Lean Construction is a promising approach to improve productivity in the road construction sector. Lean principles have been successfully applied to optimize the processes in companies and projects. Training is a relevant part of sustainably implementing Lean Construction. Simulation games are very suitable to impart lean principles and prove to be an important supplemental tool for teaching.

The test run of the developed simulation game was successful. The framework and challenges of a supply chain of a road construction site were successfully simulated. The participants implemented lean principles and improvements were realised. It was possible to demonstrate the positive effects of Lean Construction. The feedback of the participants in the test run was positive. Thus it is believed that the simulation game is a useful tool to improve the action competence in the field of Lean Construction. Further test runs are recommended in order to improve and fine tune the game. Once this is done it is conceivable to use the simulation game professionally.

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