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Research paper

A Simulation Game Framework for Teaching Lean Production

Ivo Da Silva
Industrial Engineer, Bosch Security Systems S.A., Zona Industrial de Ovar, 3880-728 Ovar, Portugal,
ivodasilva@ua.pt

Ana Raquel Xambre
Invited Assistant Lecturer, GOVCOPP - Governance, Competitiveness and Public Policies, University of Aveiro,
Campus Universitário de Santiago, 3810-193 Aveiro, Portugal, raquelx@ua.pt

Rui Borges Lopes
Invited Assistant Professor, Department of Economics Management and Industrial Engineering, University of
Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal
CIO – Operations Research Center, Faculty of Sciences, University of Lisbon, 1749-016 Lisbon, Portugal,
rui.borges@ua.pt

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Abstract

This paper introduces a new physical simulation game framework, which can be used in a classroom environment (for both students and professionals) to help demonstrate the applicability as well as the potential advantages of lean production. The game provides a hands-on experience, focusing on experimental learning, and thus enabling students/trainees to get a deeper understanding of the lean principles. The use of simulation games is not, however, restricted to teaching, as it can also be used to test real-life implementations of production systems. By using the proposed game framework, professionals may have a cheap alternative to expensive simulation software.

The game starts out by creating an unbalanced system. Throughout the iterations of the game, lean principles are introduced and implemented in the system, thus allowing students/trainees to understand how lean production can be implemented in organizations. The game elements, design of the initial system, as well as subsequent iterations, are presented and briefly discussed.

Key words: *Education, Industrial engineering, Lean production, Simulation game*

1. INTRODUCTION

Lean production, popularized by Womack *et al.* [1] and Womack and Jones [2], aims to enhance ‘customer value’ and reduce ‘waste’. Customer value can be defined as any action, process, feature, or service that a customer would willingly pay for. Waste, also referred as *muda*, is considered any expenditure of resources (activities or products) that does not add value to the customer.

Lean production principles have become increasingly popular in industries, where its practices have become a necessity for facing competition in the current global market. For a comprehensive review and a detailed historical account of the key events and major publications in lean production see [3, 4].

As lean production principles and tools became more and more prevalent, engineering and management schools started including them in their courses [5]. Additionally, an increasing number of industry training programs address lean [6]. Students and trainees attending these courses/programs are therefore expected to have a real grasp of the main lean principles and tools.

For teaching lean, or even other production principles and strategies, several approaches exist. Typical approaches consist of, among others, industry projects, case studies, computer simulations, and company visits [7, 8]. These approaches, however, focus on passive learning, which are typically less effective than active learning approaches [9]. One way of active learning is simulating the real-world experience, in order to provide the best possible memory recollection. This is called experimental learning which, in the case of production-related courses/programs, is hard to teach/apply in a classroom setting [10]. Thus, classroom games have become increasingly popular as an effective active and experimental learning approach.

Several lean simulation games have already started to appear in the literature. Some focus on specific lean tools [5, 11], while others aim at demonstrating specific concepts [12, 13]. A comprehensive review and future research directions of these games can be found in [14]. All of these works help support the notion that games and simulation studies are an effective way of teaching lean. Still, most of these games are either not well documented, require special (costly) kits, too simplistic, or too complex [7].

The aim of this paper is therefore to propose a new physical simulation game framework. The game framework is well documented, with moderate complexity, and has few implementation requirements (in terms of cost, materials, and participants), making it easily replicable.

Although mainly directed at implementing and demonstrating lean production principles and tools, throughout the development of the game several opportunities arise where other production-related tools and methods may be addressed (both theoretically as well as in the game). This makes the game prone to also be used in an introductory production-related discipline or training, more so, as it can be used in a classroom environment with little requirements.

The paper is organized as follows. The game main elements are presented in Section 2. These include the chosen product, the corresponding assembly operations, a proposal for an initial layout, and the game participants. Afterwards, in Section 3, the game rules and iterations are presented, accompanied by a proposal on how lean principles and tools can be introduced in the game. Finally, conclusions and an outlook on future work are presented in Section 4.

2. GAME MAIN ELEMENTS

In order for the game to work, several elements had to be defined. The first element of the game to be set was the product to be used. The product had to meet some conditions, namely, it should be easy to carry and cheap to obtain, the product's assembly should be of moderate complexity, having several components, and the components should have strong mechanical resistance (as it should be reassembled several times). Based on these conditions, the product chosen was the 3 pin electrical plug UK type. An imaginative reader can easily find a product with similar characteristics, and adapt it to the proposed game framework.

For the game size proposed in this paper 42 plugs are required. In Figure 1 it can be seen the electrical plug (left) and its components (right). The components descriptions can be seen in Table 1.

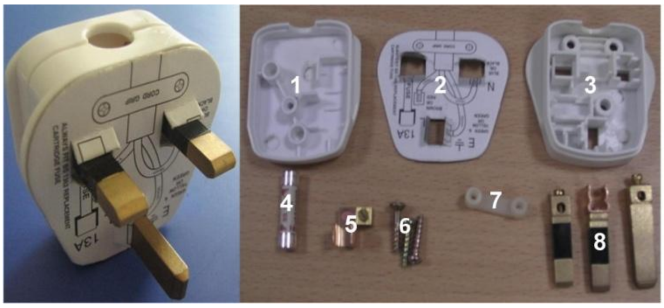

Figure 1. Three pin electrical plug UK type (left) and its components (right)

After setting the product, the remaining main game elements were defined. These include the product assembly operations, the initial layout and operations assignment, the game participants, and other game elements (such as product differentiation, production documents, additional layout areas, etc.). In the following subsections these elements will be described.

Table 1. Electrical plug components description (Figure 1)

Components
1 – Back cover
2 – Instructions card
3 – Front cover
4 – Fuse
5 – Fuse support
6 – Screws (type A and type B)
7 – Cable holder
8 – Pins (simple, fuse support, and big)

2.1 Assembly operations

The electrical plug has 11 different components that are to be assembled in 11 distinct operations. For additional realism, two operations were added: packaging and labelling. The packaging is made using a 10x10 cm airtight bag, and the labelling requires sticking a label on the airtight bag according to the type of plug (three different types of plugs exist, which will be described later).

For the electrical plug a precedence diagram was obtained, with corresponding normal operation times. Using these, it was possible to assign tasks to workstations (WS) defining, in this manner, the assembly sequence, aiming at providing a set of easy to perform operations. The definition of the precedence diagram, obtaining the times, and defining the assembly sequence may be left to the students/trainees. This leaves room for introducing production-related concepts (in case of introductory courses). The proposed assembly operations can be seen in Table 2, while the precedence diagram and an exploded view of the assembly process (without packaging and labelling) is depicted in Figure 2.

Table 2. Assembly operations and precedences

Assembly operation	Precedence
a) Insert two screws type A	–
b) Put the cable holder	a
c) Insert simple pin	b
d) Insert big pin	b
e) Insert pin with fuse support	b
f) Fit fuse on the support	–
g) Fit fuse support	f
h) Fit fuse on the pin with support	c, d, e, g
i) Assemble back cover	h
j) Insert screw type B	i
k) Insert instructions card	j
l) Packaging	k
m) Labelling	l

2.2 Initial layout and operations assignment

The definition of the initial layout (and corresponding operations) is, by itself, an opportunity to address an important subject within operations management. Techniques such as work measurement, assembly line balancing, layout design [15] may be introduced, allowing the students/trainees to build their own layout. If this is not intended, the game instructor may provide a predetermined layout with the operations to perform at each WS.

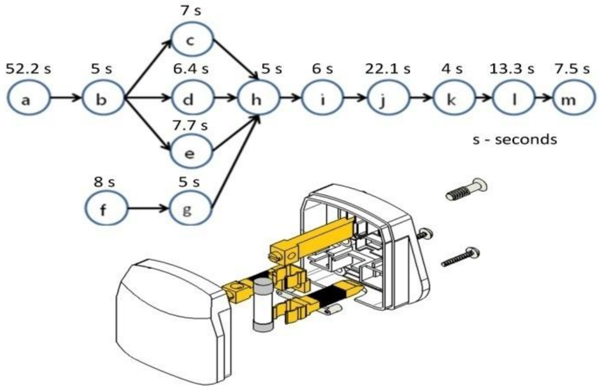

Figure 2. Precedence diagram (with operation normal times in seconds) and exploded view of the assembly process

An example of a usable layout can be seen in Figure 3. The operations and standard time per WS (which had to be measured since it does not correspond to the sum of the operations individual normal times) are shown in Table 3.

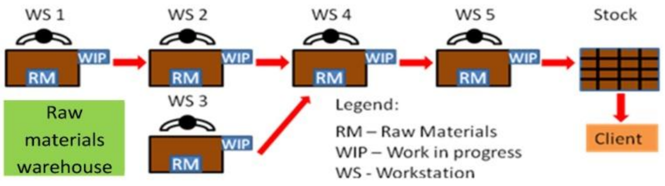

Figure 3. An example of an initial layout

Note that this initial layout does not need to be balanced. In fact, if an unbalanced system is initially used, it will allow the game participants to experience even more improvements later on.

Table 3. Operations and corresponding standard time per WS

WS	Operations	Time (s)
1	a, b	58.5
2	c, d, e	21.1
3	f	8.0
4	g, h, i, j	38.1
5	k, l, m	24.8
	Takt time	21.4 s/plug

2.3 Other game elements

For providing additional complexity and realism to the game additional concepts and elements were introduced:

- product differentiation
- work instructions
- client's demand
- production orders
- client's demand forecast
- specific layout areas.

As in most production systems there is product differentiation. In this game three different types of plugs are used, differing among them the type of fuse. The amperage of the three types of fuse is 2, 7 and 13 ampere and there are 14 plugs, of each type, available.

The work instructions are to be given with full detail, allowing the participant to grasp the difficulty of interpreting and understanding such instructions (allowing the introduction of visual management concepts later on).

As in real life, the game's main goal is to fulfil the maximum number of client's requests. The client's demand is going to be the same throughout the game, therefore allowing to easily determine advantages and disadvantages of implementing lean tools (using as measure, the ability to fulfil the client's requests). The client's demand will match the current *takt* time (2.8 plugs/minute). The required quantities, as well as the type of plug, will be asked on a minute-by-minute basis, and will only be revealed on the exact minute the quantity is required.

Production orders (PO) were also introduced. According to the proposed assembly operations (Table 2) and initial layout (Figure 3), product differentiation occurs in WS 4, being supplied by WS 3. Therefore, PO are to be delivered to these two WS. There is no set criteria for operators to define the PO's priority (order in which it will be fulfilled). In each iteration no more than four PO can be released, and once the operator starts fulfilling a PO that same order cannot be withdrawn (which will most likely result in some entropy in the system).

A client's demand forecast can also be used, to help the person responsible for releasing the PO (the planner). The forecast predicts the number and type of plugs in intervals of 5 minutes (not allowing the planner to predict what type of plug will be asked in the current minute). The planner will have three PO for each interval and an extra one to correct possible PO mistakes.

Within the layout, several areas were defined. The main areas, their proposed location and purpose can be seen in Table 4. There is no specific format for these areas, however, they should be in accordance to their specific purpose and distinct from each other.

Table 4. Proposed areas, location and purpose

Area	Location	Purpose
WIP	After each WS	To stock WIP made by the previous WS and for the next WS to realize the next work to perform
Finished goods	After the last WS	To store all the finished goods that weren't dispatched and to alert the dispatcher to the current availability
Delivered goods	Close to the finished goods	To where all the dispatched products must go
Warehouse	Apart from the production system	To store components

2.4 Game participants

The advisable number to start the game is 10 participants. This number is directly related to the initial layout. If the layout has less WS, fewer participants are needed. Table 5 displays the number of advisable participants per role and corresponding role description. If the number of available participants is insufficient, the instructor may take part, taking on the role of time collector.

Table 5. Number of participants per role, and role description

Role	Description
5 Operators	Worker assigned to each WS for assembling the components
1 Dispatcher	Responsible for checking if there are enough finished goods to dispatch to clients
1 Planner	Person in charge of scheduling the production and releasing PO
3-5 Time collectors	Obtains the cycle times (CT) of the WS

Moreover, if it is not intended to draw conclusions on the outcome of the new balanced line (see Section 3.2), the role of time collector may be disregarded. In each WS, the cycle time (CT) starts from the moment the operator picks up the work in progress (WIP) from the previous WS and begins assembling the raw materials (RM), and finishes when (s)he picks up another WIP from the upstream WS.
Since the line is unbalanced the cycle times of each WS are different. As the game unfolds the cycle times of the WSs should converge to the *takt* time.

3. GAME RULES AND ITERATIONS

Before the game starts it is necessary that the participants are aware of the game rules. These rules may change as the game unfolds and according to the subjects the instructor wants to address, and also the target audience. The game was initially developed to have three iterations, where, gradually, lean concepts and tools are introduced. In the following subsections the three proposed game iterations will be presented.

3.1 First iteration: production system before implementing lean concepts

In the first iteration it is required the existence of WIP between each consecutive WS (in the respective area). This rule has two main goals: to teach the operators the assembly operations they will have to perform in their WS; and to simulate the scenario where some PO were left unfinished in the previous day. The planner also has to release a PO before the trainees start to learn the operations assigned to them.

As there is no replenisher, operators must supply themselves. They may move to the warehouse to obtain raw materials, but are advised not to take all the components from the warehouse.

All WS have a container for each component (which may start by not being identified, allowing the participants to discover, by themselves, the need to do it). As the stock for each component may run out at different times, waiting times may exist, making participants aware of a possible balancing/layout problem.

In the warehouse the components must also be divided into different containers (which, again, may start out by not being properly identified). Concerning the dispatcher, (s)he can only dispatch products if the previous order has been fulfilled, otherwise (s)he needs to wait for the required finished goods.

One final aspect is how the WIP is moved from WS 4 to WS 5 (in the proposed initial layout). In WS 4 the back cover of the plug is assembled, not allowing the distinction of the type of fuse from there on. Participants are encouraged to find a solution for this (possibly using three identified containers between these WS).

3.2 Second iteration: implementing the first three lean principles

The second iteration starts with the first lean principle: specify value. All operations must be reviewed in order to identify and eliminate non-value added work. For example, identifying unnecessary movement, such as the trips operators have to perform in order to supply themselves.

Afterwards, the following lean principle is introduced: map the value stream. For this iteration value stream mapping (VSM) should be used to map the system. VSM allows to easily display key aspects such as the difference between lead and processing time, bottlenecks, the amount of WIP, and possible improvements. The VSM can be made by hand (as seen in Figure 4) with the current and future state map.

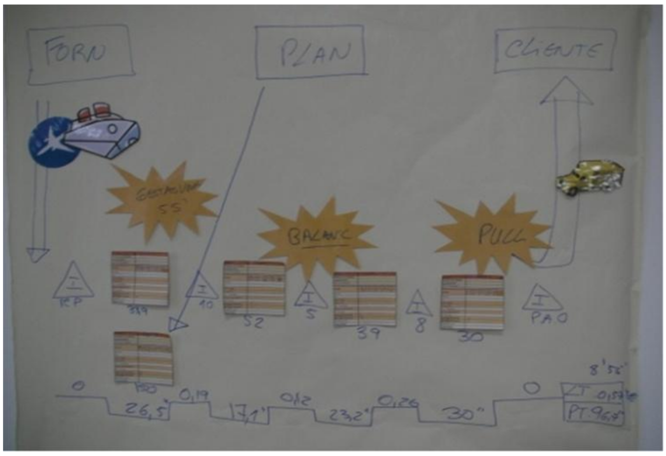

Figure 4. VSM example made during the game development

In order to achieve the lean principle create flow, a balanced system is required. Therefore, participants are encouraged to develop a balanced system. For the proposed initial layout a new assembly line, with only 4 operators can easily be thought off. This balancing tries to achieve two goals: obtain continuous flow, and release one operator. It should be noted that, although this game only considers assembly operations, the balancing can easily be adapted to address manufacturing lines/cells examples.

3.3 Third iteration: applying lean tools

In the third iteration the mapping process must be performed again, thus allowing participants to acknowledge the results of the implemented changes. In this iteration, six lean tools are to be addressed:

- *kanban*
- visual management
- one-piece flow
- supermarkets
- *mizusumashi*
- point-of-use-storage.

Figure 5. Containers with *kanban* cards

By using *kanban* we are also introducing the fourth lean principle: pull philosophy. *Kanbans* will be delivered by the dispatcher to the most downstream WS. There, a *kanban* post [16] will guarantee the *kanban* cards follow the correct order. The *kanban* cards can be inserted in the containers (Figure 5) specifying the container's component and corresponding quantity. An empty container will trigger the need to supply that specific component.

Visual management will help differentiate the types of product by colour, instead of fuse amperage. In the WS where product differentiation occurs (in the newly balanced system) containers may be replaced with areas with colour codes (as shown in Figure 6). Also, the fuses must have the same colour that was defined by the colour system (e.g. the fuse with 2 amperes in Figure 6 has the colour green).

To guarantee the one-piece flow, another rule is introduced: in the areas with colour codes it can only exist one product of each type. Every time the corresponding WS removes one type of WIP from the areas, the upstream WS can start working to replace the WIP corresponding to the empty slot. The same rule applies for the remaining WS.

Two kinds of supermarket were defined in this game: one for the finished goods (Figure 7) and another for the warehouse (Figure 8). For the finished goods, the size of the supermarket should allow, at most, 3 plugs per type, and the system must always produce for the supermarket. For the warehouse, the supermarket concept will be limited as there is no other system supplying the warehouse. Therefore, components are divided into the same amount per container (according to the incorporation factor), as seen in Figure 8. By having the same amount of components per container, when a component runs out of stock, all the remaining components also run out of stock.

Figure 6. Areas with colour codes for each type of fuse (from left to right, 2, 7 and 13 amperes)

Figure 7. Finished goods supermarket with colour code

Therefore, all the supply needs occur at the same time, and can be met at once. The supplier, called *mizusumashi* (*mizu*), is required to start supplying at the last WS in an upstream direction, as the system is operating in a pull philosophy. Moreover, the *mizu* supply is triggered when a container in the last WS becomes empty, where (s)he is to collect the empty container in each WS and exchange it with the container in the supermarket. To help the *mizu*'s task a dashboard can be made (using visual management) with pictures of the components divided according to the WS in which they are used.

Since waiting times are to be avoided, in each WS it can be introduced a 2-bin replenishment system, point-of-use-storage (POUS). With this new system every time a container runs out of components a backup container can be used. When the operator empties a container (s)he should place it on the lower shelf of the POUS to trigger the *mizu*, and the backup container will fall, making it available to the operator.

At this point, the proposed lean tools are implemented in the system. Therefore, the instructor can obtain the current system times (if time collectors were used), and with them, as well as the currently available data, enter into a discussion phase with the students/trainees. Here, students/trainees are encouraged to provide additional ideas on how to improve the system, thus allowing to introduce the fifth and last lean principle: seek perfection.

Figure 8. Raw materials warehouse supermarket

4. CONCLUSIONS AND FUTURE WORK

This paper presents a game framework, based on the assembly of an electrical plug, developed to be used in a classroom environment. Although focusing on the implementation of lean production, it enables the introduction of several other production-related concepts and tools. Moreover, the proposed framework provides a low-cost alternative to expensive simulation software, to test real-life implementations of production systems.

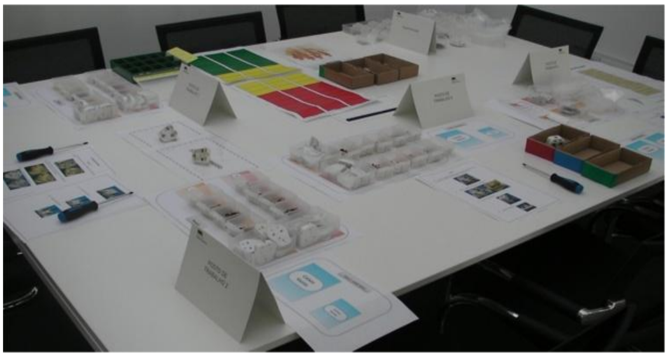

Figure 9. Overview of the proposed game framework

During its development, the game was tested in a training session with participants with little knowledge of lean production. Although the game can be used in one or several sessions, with no predetermined time, in this case, the session was one hour long. The main objective of the session was to test the proposed game framework, regarding the applicability of lean production principles and tools. Positive feedback was obtained, as participants experienced the problems of unbalanced push systems and quickly grasped the presented concepts.

Although more tests sessions (with different target audiences) have still to be performed, the proposed game framework seems a promising tool to introduce lean production concepts. The game is not too complex, while still being effective, allows a hands-on experience, and has few implementation requirements (in terms of cost, materials, and participants). An overview of the proposed game framework can be seen in Figure 9.

As future work it is proposed the introduction of additional lean concepts such as heijunka box, poka-yoke systems, 5S, and single-minute exchange of die (SMED), possibly using additional iterations. Also, pre- and post-game surveys may help to further understand the benefits of using this type of games in a learning or training environment.

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Okvir simulacione igre za podučavanje LEAN pristupa proizvodnji

Ivo Da Silva, Ana Raquel Xambre, Rui Borges Lopes

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Rezime

Rad uvodi novi okvir fizičke simulacione igre, koji se može koristiti u učionici (i za studente i za stručnjake) radi demonstracije primenljivosti i potencijalnih prednosti lin pristupa proizvodnji. Igra obezbeđuje praktično iskustvo, fokusiranjem na eksperimentalno učenje, omogućujući studentima/polaznicima da dublje razumeju lin principe. Upotreba simulacionih igara nije ograničena na podučavanje, takođe se može koristiti za testiranje realnih implementacija proizvodnih sistema. Upotrebom predloženog okvira za igru, stručnjaci mogu imati alternativu za skupe simulacione softvere. Igra počinje sa neuravnoteženim sistemom. Kroz iteracije tokom igre, lin principi se uvode i implementiraju u sistem, dozvoljavajući studentima/polaznicima da razumeju kako se lin pristup proizvodnji može primeniti u organizacijama. Elementi igre, dizajn početnog stanja sistema i kasnije iteracije tokom igre su prezentovani i raspravljani.

Ključne reči: *Obrazovanje, Industrijsko inženjerstvo, LEAN proizvodnja, Simulaciona igra*