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SIMULATION AND GAMING AS A SUPPORT TOOL FOR LEAN MANUFACTURING SYSTEMS – A CASE EXAMPLE FROM INDUSTRY

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ABSTRACT

In this article we illustrate how simulation and gaming can be used to support lean manufacturing systems. More in particular we study a case example from industry – a manual assembly line for mail-inserting systems – for which we have developed a simulation game. This paper focuses on the development steps of the simulation game. The objective of the game is to support the introduction of lean principles in an existing assembly line. The simulation game can be used to demonstrate applicability of a lean control concept at the assembly line and to train workers to make appropriate control decisions within this concept. In this paper, we indicate a definite need for the development of this game. The systematic way in which it is developed, the use of a general simulation language in the design phase, and its usefulness may stimulate the introduction of simulation games in more industrial settings.

1 INTRODUCTION

In recent decades new concepts of doing business have emerged such as lean manufacturing and agile manufacturing (Womack et al. 1990, Goldman et al. 1995). They present an answer to changed market conditions like intensified, global competition and changing customer expectations. Consequently, there is a need and opportunity for adapting and replacing current manufacturing systems in industry. In this article we study this issue by considering the redesign of a manual assembly line for a manufacturer of mail inserting systems (Kalk 2005). Basically, mail-inserting systems fold, fill and close envelopes in an automated way, see Figure 1.

The company implemented a new assembly line for mail inserting systems in early spring 2004. Its design is motivated by the principles underlying lean manufacturing. After a few months of operation – allowing for start up problems to be solved – it became clear that the line did not meet its targets. Basic problems were related to product quality, material shortages, throughput, and worker inefficiencies. Concerning quality and material shortages, adequate measures were taken in the subsequent months. The problems with respect to throughput and efficiency, however, required further analysis. It became clear that the control concept for the line was not transparent and not complete. The predetermined control rules were not used in practice. The control concept also did not take into account worker differences with respect to skills and working speeds. The impact of these factors on system performance is relevant in this case. The assembly operations are relatively complex and the variety of worker efficiencies is large. A further complicating aspect is that the composition of the workforce is unstable. Depending on demand fluctuations, more or less workers are assigned to the line.

Figure 1: Mail Inserting System

As a response to the existing control problems, a new control concept – takt-time control – has been defined, that takes notice of both production targets and worker characteristics. In principle, the new concept provides an answer to the earlier mentioned problems faced by the company. It, however, does not present a solution to the problem of distributing assembly tasks among workers within each line segment. At first sight this problem may seem fairly simple to solve by adopting rules like "down-up", or "up-down", which send idle workers downstream or upstream to search for a new job. Such rules, however, do not consider job variety and worker differences.

Another issue that has to be solved, concerns the acceptance of the proposed control solution by the workers and the management. Management is only willing to implement the solution and to make the required investments (for example, software, screens for monitoring line operation, training time for workers) after being convinced that the new takt-time control concept has major advantages. At the same time, the takt-time control concept inhibits a natural resistance of workers; working according to takt-time can easily be associated with working-like-robots. Workers need to understand that the takt-time concept does not necessarily degrade their working conditions. In this particular case, the control concept may even upgrade the working conditions, because it puts the teams in control of their subsystem. It is important to deal with these implementation issues in the development of a lean assembly line.

In order to cope with the assignment problem and the implementation issues, the idea came up to develop a simulation game. Simulation games combine game elements (for example, human decision makers, roles, rules), with those of a simulation, i.e., critical features of reality. They are suggested for their visibility, reproducibility, safety and economy relative to real life experimentation/training (Raser 1969). The new game should facilitate (i) the demonstration of the new control concept for management and workers, and (ii) worker training on selecting appropriate control rules (i.e. where to go rules).

In this article we describe and analyze experiences obtained in the development and use of the new game. Essentially, we seek for ways in which simulation games may support new business concepts in terms of acceptance, understanding, training, and operational support. Next to that we discuss main constructional issues that follow from our idea of using a commercially available off-the shelf simulation package, EM-Plant™, as a vehicle for gaming.

The remainder of the paper is organized as follows: in the next section we will introduce a framework for game design. It is meant to structure our discussion on game development and it is used throughout the paper. In Section 3 we discuss the case example in some detail. Next, in Section 4, we describe and evaluate the new game. Section 5 presents the major conclusions of our study.

2 A FRAMEWORK FOR GAME DESIGN

In this section, we first present a framework for game design. The framework will be used throughout the paper. Next, we will consider the use of commercially available off-the shelf simulation packages (cots) for game construction.

2.1 Framework

For game design we start from the framework introduced by Greenblat and Duke (1981). Their framework has been enriched by Riis et al. (1995) building on their extensive experiences in game design and use. The framework covers the overall design process in four phases: Initialization, Design, Construction, and Operation of the game, see Table 1. We only summarize essential elements for each phase here. For a more detailed discussion we refer to Greenblat and Duke (1981), and Riis et al. (1995). Reasons for choosing their framework are the structured way it describes the design process and the possibility to use it as a reference model for the field of gaming and simulation.

2.2 Use of Cots for Game Construction

An important element in game design is the choice of software for model construction, see Subsection 2.1. Many choices are possible. A short review of games revealed that it is difficult to find a common basis in this respect, see e.g. Riis et al. (1995), and Smeds (2003), for overviews. Starting from these overviews we learned that some designers make use of general-purpose software like Pascal™ or Java™, while others report the use of simulation software such as Witness™, and Femos™. Also many game designers do not report about the choice of software.

We chose to consider the use of cots for game construction. Clearly, most cots offer many features for building valid simulation models, starting from elaborate libraries of building blocks and facilities for modeling dynamics. Also most of these packages offer additional support like tutorials, updates, hotlines or even user groups. See Swain 2003 for an overview of cots and their respective features.

Gaming is, however, not the same as simulation. The dominant simulation methodology aims primarily at the use of simulation for analysis purposes (Robinson 1994, 2001; Law and Kelton 2000). Typically, model interaction is largely restricted to the analyst, while models are only demonstrated to the problem owners. For games, user interaction is intrinsic. This puts high demands on setting up the design and construction of the interface, i.e., the display, and the possibilities for interacting with it. More in particular it was found that issues to resolve relate to the following game elements, see Subsection 2.1:

Table 1: Framework for Game Design

Phase in game design	Issues
<u>Initialization</u> Definition of scope and objectives for the game	• Consider the appropriateness of the game: are there alternative approaches that may result in better outcomes? • Specification of requirements. - Purpose of the game: e.g. describe, demonstrate, practice. - Limitations on resources and equipment. - Line of thinking: game focus, adjustment to participants, validity of mapping of real-life settings, measurability of game results. • Definition of constituent elements of a game. - Model of reality. - Scenario(s): plot(s) of the game. - Events, e.g. arrivals, break downs, urgent orders etc. - Game process: introduction, game runs, evaluation. - Periods: subdivision of game runs. - Roles: characterization of persons or jobs in a game. - Game rules: relationships between roles. - Decisions: alternative decisions allowed for players. - Results: presentation of outcomes of a game, i.e., performance realized by players. - Indicators: measurements displayed during game design. - Symbols: mapping of real-life items. - Materials used, e.g. dices, jettons, cardboard.
<u>Design</u> Basic ideas formulated in the initialization phase are worked out in detail. The outcome of this phase should be a simulation game concept, i.e., a blue print for game construction.	• Game process: picturing the real life process. • Learning process: learning experiences aimed at.
<u>Construction</u> The game is constructed by means of physical elements, software, and such.	• Engineering of elements (see Initialization). This usually sets demands to the skills of the engineer, and requires the use of materials and/or software. • Arrangement of roles of players and the game leader(s).
<u>Operation</u> The operation phase concerns the actual use of the game. This may include a test of the game for its intended purpose and workings.	• Preparation: inviting and informing game participants. • Running of the game. • Evaluation of the game process: learning experiences.

- Scenarios: How can they be effectuated? How is the model adapted to reflect a scenario?
- Events: How to display an event?
- Rules of the game: How to realize events? This questions the use of the event controller.
- Decisions: Which decisions are/are not allowed? Feedback on decisions?
- Symbols: They should appeal to players. Also their workings should be clear.
- Indicators: Which indicators should be displayed? How to display them?

Next to the above issues, another required functionality concerns facilities for analyzing decision-making. Simulation tools generally do not record human decision-making in detail. In order to use simulation, or gaming, for educational/learning purposes, the analysis of human decision-making is an essential element in the provision of feedback to the player of the game. We will discuss the here-mentioned elements in Section 4.

3 SYSTEM DESCRIPTION – A MANUAL ASSEMBLY LINE

The starting point for game design is a new manual assembly line for mail inserting systems (Kalk 2005). Basically, mail-inserting systems fold, fill and close envelopes in an automated way. Let us consider background, objectives, and main characteristics for the assembly line.

3.1 Background

The new assembly line was implemented in the beginning of 2004. It replaces an old assembly line. The old line is characterized by many non-value adding activities, inefficient design of work places, and frequent and lengthy setups due to the need for rebalancing the line and the reallocation of materials. This results in many problems with respect to product quality, lead times, throughput, and worker efficiencies. The introduction of the new assembly line is supposed to improve performance drastically.

The basis for the design of the new assembly line is the lean manufacturing concept. Essentially, the concept aims at flexible and efficient work cells by reducing waste in all forms, such as, production of defective parts, excess inventory, unnecessary processing steps, and unnecessary movements of people or materials (Womack et al. 1990). With respect to flexibility and efficiency a number of goals are set for the new line:

- Volume and mix flexibility: the line should be able to cope with fluctuations in demand volume. Also the mix of product types may change. Total daily demand may range between 20 and 40 products.
- Product flexibility: the line should be able to cope with new variants of products.
- High worker efficiencies.

Flexibilities should be realized in a controllable way. It is desirable to have a predictable output. The worker costs are a good indicator for the efficiency by which a controllable situation is realized. Costs of stations and tools are relatively small.

3.2 System Description

The new assembly line is designed and implemented by the firm in close co-operation with TNO, a government supported consultancy for innovative projects. Essential characteristics of the new system are, see Figure 2:

- 17 Stations in line. Each station can be manned by at most one worker. Average process times are in order of 10 minutes.
- Each station is decoupled from its predecessor and successor by a buffer of size one.
- The line is balanced using detailed labor studies as an input. Balancing is important to deal with high volume situations where the worker/station ratio is high.
- An efficient setup of workplaces, by cutting non-value adding activities.
- A deployment rule for assigning workers to stations.

Volume flexibility is realized by varying the number of workers at the line. If the line has to operate at maximum capacity all stations are manned (by one worker each). In case of a lower demand, the work force is reduced accordingly. Consequently, workers then are responsible for operations at more than one station. In periods of moderate and high demand temporary workers are hired.

Figure 2: The New Assembly Line

In order to gain a controllable assembly line, the firm has split the line in three segments. A team of workers is assigned to each segment. Team activities are coordinated using the takt-time principle (Baudin 2002). Essentially, the takt-time principle foresees in line pacing by considering a fixed time frame – the takt–time – in which each team should complete assembly operations for one product. The respective product is to be placed in a buffer and serves as an input for a successor segment of the line. The setting of the takt-time is based on demand figures. Essentially, it relates planning period and its associated demand.

To increase line flexibility as well as worker efficiency the worker team for each segment is pooled with a team of workers responsible for subassembly operations. In principle, only subassembly workers that act as suppliers for the respective line segment are involved. Given the presence of a relatively large buffer for subassemblies, subassembly workers may be assigned to the line on a temporary basis. On the other hand, in case of worker idleness on the main assembly line, the line workers may be assigned to subassembly operations.

As mentioned in the introduction, the issue of 'where to go after finishing an operation' is of major importance for the control of the assembly line. The game, which will be presented in Section 4, is meant to teach workers how to make appropriate 'where to go' decisions. This issue is strongly connected with the establishment of well-working teams: workers have to learn that appropriate 'where to go' decisions require a team view. The proposed game is meant as a tool teaching workers to make good decisions and, therefore, will support the realization of such a team view. At the same time the game experience should increase workers' and management's confidence in the quality of the solution.

4 A NEW SIMULATION GAME

In this section we will describe and evaluate game development and use. To structure our discussion we will use the framework for game design introduced in Section 2. It specifies phases in game design and issues to be addressed. More specific, we consider the use of cots for game design, building on the use of the tool EM-Plant™ for game construction.

4.1 Initialization

In this first step we consider purpose of the game, alternative approaches to gaming, requirements and a definition of the constituent elements of the game.

4.1.1 Purpose of the Game

In the introduction we sketched the initial problem faced by the company: the new assembly line does not meet company targets on throughput and worker efficiencies. The new line concept, as described in the previous section (teams of workers, takt-time-controlled) has been implemented at the end of 2004. Before implementing, it was necessary to familiarize both the management and the workers with the new control concept. Both parties set different demands. While for the management an insightful demonstration of the concept would be sufficient, convincing workers also requires the incorporation of some training. Workers need to learn the meaning of the takt-time-control concept and the importance of making team-based 'where-to-go' control decisions.

4.1.2 Alternative Approaches

A simulation game was seen as the most appropriate means to realize the learning effect. However, alternative approaches like lecturing and training on the job received due attention. They have both been applied by the company. In fact their shortcomings laid the basis for the decision to consider the gaming approach. Let us shortly evaluate both alternative approaches. This helps in highlighting the added value of the gaming option on the one hand, and the relevance of game specifications on the other hand.

Training on the job may be advocated as the best approach to learning (Ruohomaki 1995). However, given the case settings, this approach faces major disadvantages. Firstly, it is difficult to give appropriate and quick feedback to workers on the impact of their control decisions. Typically, the impact can only be seen after some time – after completing several (subsequent) operations. This time span is problematic for a clear understanding of "cause and effect". Furthermore workers have to cope with a complex assembly task, which requires cognitive efforts. Secondly, in case of training on the job, the learning intensity is low. An assembly operation takes about 10 minutes, while control decisions will be made in a matter of seconds.

As a first attempt for realizing the learning effect the company made use of lecturing, building on a series of sheets made using MS Powerpoint™. It demonstrated the principles underlying takt-time control. While the lecture increased understanding among workers and management, it was plagued by a number of flaws:

- Experience of the attendees is limited – they may watch model dynamics, but are not able to influence model behavior. Consequently, only a limited contribution is made to their confidence in solution quality.
- Little attention is paid to the problem of worker deployment – what would be adequate rules? To be used under what circumstances?
- Little insight is obtained in relevant worker and job attributes.
- Team coordination and team building are no issues. After all, it is the team of workers that has to stay in pace, i.e., deliver a new product every period.

4.1.3 Requirements

From the above evaluation of alternative approaches a number of requirements may be distilled for game design. The game should:

- Isolate control activities from operations with respect to learning.
- Allow for decision-making under various scenarios. Scenarios are defined by worker and job characteristics, as well as system status, i.e., the distribution of products over the line.
- Allow for a team-focus on line control.
- Offer the possibilities to analyze decision-making by players, i.e., the way in which their where-to-go decisions influenced system status and overall results.

These requirements refer to game design. The experience resulting from game use should strengthen players' confidence in the quality of the new control concept. Here quality refers both to worker well-being, and logistic measures like throughput and worker efficiencies.

Additional demands with respect to game design concern its re-use (i) for training of newly hired workers, and (ii) as a means to support continuous improvement of worker decision making. Replaying a decision-making-game may help to move towards new and better deployment rules which fit to the specific situations faced by the assembly teams. For example, the introduction of alternative product types may have a significant impact on line control.

Finally, restrictions are set to the budgetary means for game setup. This refers to the efforts and financial resources to be put in game design and use. For example, playing times should be kept to a minimum, as workers have to be withdrawn from their actual duties.

4.1.4 Constituent Elements

Starting from the game purpose, case settings and elements have been defined, see Table 2. It shortly characterizes each of the elements.

Table 2: Game Elements.

Game elements	Definition
Model	Segment of assembly line
Scenarios	• Alternative control rules – paced (takt-time), unpaced • Alternative settings for worker and job attributes – working speeds of workers (homogeneous, inhomogeneous); norm time per operation
Events	• Intake of new products, completion of jobs
Game process	• Introduction by game leader – problem and solution • Gaming: line operation – developing rules for worker deployment • Resume: evaluate learning effects, discussion
Periods	-
Roles	• Line manager
Game rules/ Decisions	• Related to control rules
Results	• Throughput, average flow time, ability to produce according takt times.
Indicators	• Distribution of products over the line, Time left to stay in pace
Symbols	• Work stations, buffers, products, workers
Materials	-

The model refers to just one segment of the line. This is a natural choice as teams are related to line segments. It is also a logical choice, as line segments may be considered rather independent of each other, being decoupled by a relatively large buffer. Relevant line elements (symbols) are workers, buffers, stations and products. Scenarios may be defined by setting worker characteristics (working speeds), operation characteristics (norm times) as well as line pacing (yes/no). The latter setting allows for a comparison of a situation assuming takt-time control with a situation where there is no line pacing.

Essentially, decision-making is to be triggered by events such as a job completion (a worker becomes idle), and a product arrival (a new opportunity to start a job). At such a moment the player having the role of a line-manager may decide to start a new job by assigning a worker to a station. Obviously, within the rules of the game, it is only possible to assign (i) idle workers to (ii) stations that are not blocked and (iii) for which the input buffer is full.

System status is indicated by the distribution of products over the line, and the time left to stay in pace (in case of takt-time control). Results of a game run to be reported are throughput, average flow time of products, and the ability to produce according takt-times. The latter ability is related to the number of times takt-time is not met, and the cumulative excess time.

Before playing the computer game, the players (i.e. the workers in their role of line managers) are introduced to the subject of assembly lines. Trade-offs in control decisions are discussed. Also the working of the model is demonstrated. Gaming concerns a series of game runs. Each game run corresponds to a scenario. These scenarios reflect real-life situations at the work floor. During a game run the players have to make control decisions. After each run learning experiences and initiatives towards rule construction are recorded by means of a questionnaire. The final part of the game concerns an overall evaluation using the outcomes of the questionnaire as a basis for discussion. In turn this evaluation should serve as a starting point for team coordination.

An important choice for design concerns the roles to be played. In the game a worker has to play the role of a line manager. This “shift of roles” is meant to prevent a rather myopic focus on optimizing the worker’s own tasks. Instead it stresses the importance of team coordination through a dedicated allocation of workers. In this respect dedication relates to relevant worker and job attributes. Note how such an approach is in line with lean concepts and supports the well functioning of cross-functional teams.

4.2 Game Design and Construction

For the construction of the model the simulation tool EM-Plant^{TM}, i.e., the successor of Simple++^{TM}, has been used.

It is one of the very few truly object-oriented simulation tools (Law and Kelton 2000). The model has been built in accordance with the choice of game elements, see Table 2.

The model concerns a segment of the assembly line – 5 stations. It allows a single player to make decisions on worker deployment by dragging worker icons to respective stations (Figure 3). As an input for decision making a player may consider shop status, i.e., the distribution of jobs and workers over the line, and several indicators, see the upper right corner of Figure 3. Alternative scenarios may be chosen by changing the experiment number in the display – top of the model, in the middle. Worker and station settings are reflected by setting their labels accordingly. For example, an employee working at 75% efficiency is labeled as such, see Figure 3.

Game runs take about one half hour per scenario. During a run, decisions are recorded for further analysis. After each scenario learning experiences and initiatives towards rule construction are collected by means of a questionnaire.

4.3 The Use of Cots for Game Design

For building the model the simulation tool EM-Plant™ has been used. It proved to be a flexible tool for representing various scenarios. Other scenarios can be easily included, such as, for example, the presence of alternative types of products. Other important gaming elements, like events, symbols and indicators can be represented in straightforward manner. For example, symbols can often be represented by building blocks available for the tool. Also indicators can easily be represented in various formats, such as strings, bars, charts, pies etc.

More attention has to be paid to decision-making and event control. Important aspects of decision-making are decision moments and decision options. The first aspect relates to those events that may trigger a decision of the player. For example, important events in our game concern product arrivals and the completions of operations, see Subsection 4.1. Each time such an event happens, model activities are halted, and the player is prompted for decision-making. Note that this implies a decoupling of simulation time and real time. Given a decision moment the player may choose from a number of decision options.

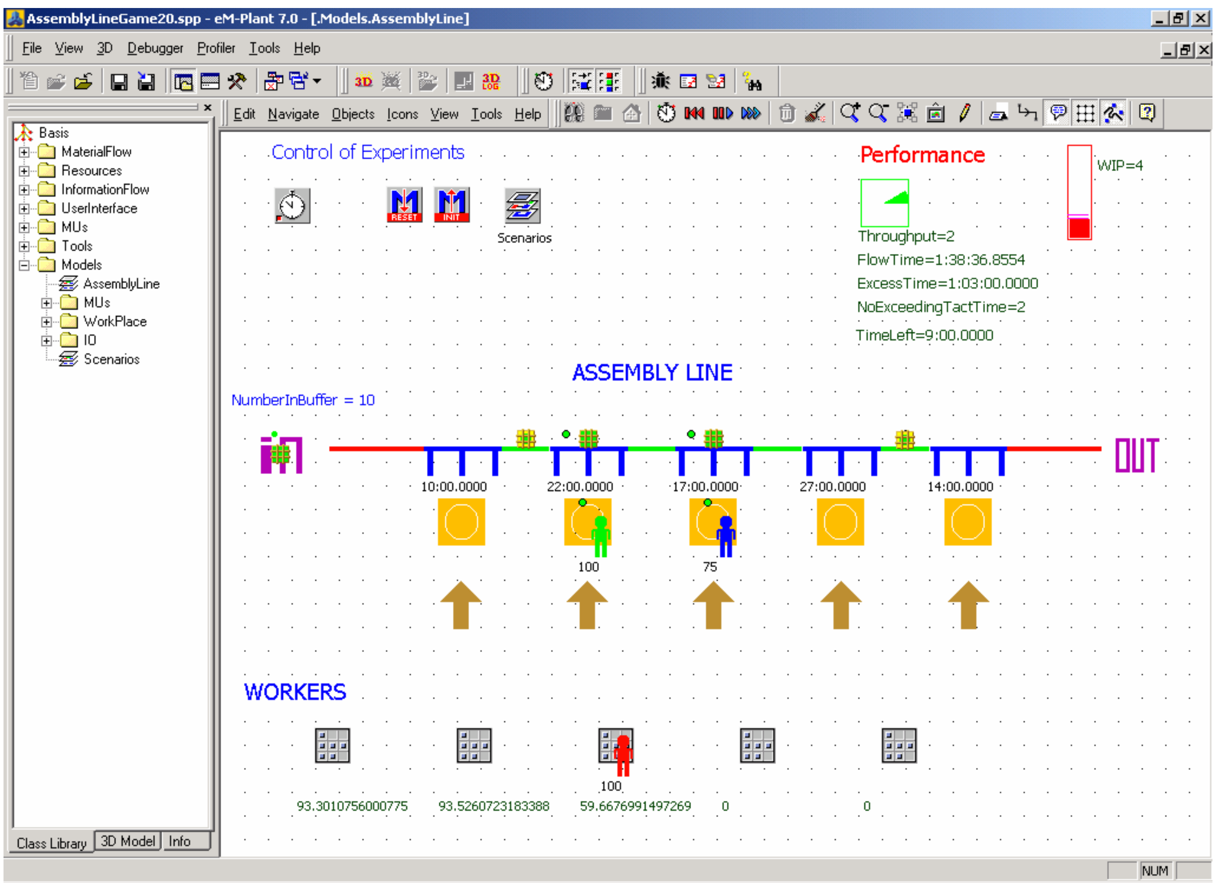

Figure 3: A Simulation Game for Teaching – EM-Plant™ Model

For our game this refers to the assignment of one or more workers to stations - by "dragging" them to the respective stations. It should be remarked that it is also possible to postpone a decision, i.e., do nothing – in anticipation of better opportunities in future. After decision-making, model activities are continued by confirming a decision option. For the EM-Plant™ model this boils down to pressing the start button for the event controller. To deal with the cases that players choose an illegal decision option specific error messages are defined that alert players using pop up boxes. At the same time the player is allowed to choose an alternative option. For example, if a player assigns a worker to a station that is blocked or starved, the worker "returns to" (is placed back in) the worker pool.

An additional facility we included in the model concerns the analysis of decision-making. Where simulation tools generally foresee in a trace of events by means of text or a film of model operation, they do not record human decision-making in detail. For example, it may be interesting to reconsider deployment decisions made by a player. In that case an overview of decisions made during a game run is required, i.e., a sequential series of assignments of workers to stations. The overview may be used to replay the game and consider the consequences of alternative decisions.

The extensions of the simulation model for game use could be realized rather easily building on the internal language of EM-Plant™. This language offers many facilities to support user interaction, and to intervene in event control. This points at an important technical restriction with respect to the type of simulation tools to choose for game design. To deal with the required extensions preference should be given to simulation languages over so-called simulators, i.e., simulation tools that foresee in the building of models relying on a pre-defined library of parameter driven building blocks. The structure of modeling facilities may make these tools unfit to deal with the flexibilities required for gaming, in dealing with human decision makers.

4.4 Game Operation

The game has been tested by about 60 university students. We have chosen to test the 'quality' of the game by means of playing the game by a rather large group of students. This setup allows for statistical analysis of game use and its appreciation. The students individually played the game in order to learn about takt-time control and to understand the impact of heterogeneity of workers and variability of station times on the control rules to be applied. The game was used as an embedded part of two undergraduate courses on manufacturing system design and control.

It was interesting to see the student's enthusiasm. Many students skipped coffee breaks, and some students even tried to improve their scores by repeating game runs, i.e. scenarios. From their questionnaires, it appears that students did their best in making contributions to rule construction. General evaluation showed that students' understanding of assembly line design and operation has been increased. These effects can also be expected in case of playing the game by assembly workers. Even more, playing the game will give the workers insight in the performance of their own control rules used at the working place. This insight is a first step towards improvement.

The main experimental factors in the chosen scenarios were (i) working with or without takt-time concept and (ii) the presence of homogeneous or heterogeneous workers. The first factor was meant to study the impact of takt-time control on the ease of selecting a good control rule (i.e. where-to-go-rule-after-finishing-a-task). The second factor was chosen to check whether or not the presence of heterogeneous workers requires more team focus in the selection of control rules.

As a general outcome, the students experienced takt-time control as more complex. This is obvious, because according to the takt-time concept they have to obey periodic output demands, while in the non-takt-time scenario's the only goal was to maximize the output in the terms of throughput. The total throughput in the takt-time scenarios is, in the game settings, only about 1% less than in the 'open' scenario, see Figure 4. This shows that the introduction of the takt-time concept only deteriorates local (one section of the assembly line) performance in a limited manner.

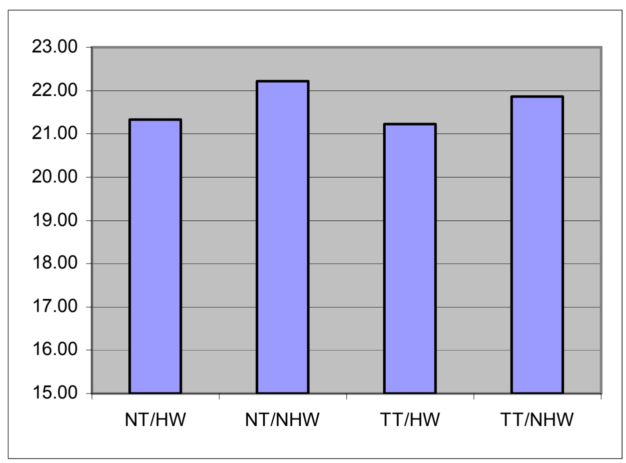

Figure 4: Average Throughput per Scenario (NT=No Takt-time Control; TT: Takt-time Control; HW = Homogeneous Work Force; NHW = Non-Homogeneous Work Force)

The presence of a heterogeneous workforce complicates, according to the students questionnaires, the realization of takt-times. Also quantitative measures like the number of times tact time was exceeded show the increased complexity - it is more often difficult to realize the takt-times. On the other hand, the presence of heterogeneous labor supports the realization of a slightly higher throughput. This is due to the fact that fast workers can be assigned to bottleneck stations, which helps to balance the system. This result expresses the need for taking the qualifications of all workers into account when making 'where-to-go-next' decisions. Students have expressed this in the control rules which they have designed/chosen in the particular scenario (takt-time, heterogeneous). By doing so, they show that the game may support team-thinking, if needed.

5 SUMMARY OF MAIN FINDINGS

In this article we discussed the use of simulation games for mastering new business concepts like lean manufacturing and agile manufacturing. To do so we studied the development and use of a new game. It refers to a case example from industry – the operation of a manual assembly line.

We found the developed simulation game to be an adequate means for supporting and improving the design of the manual assembly line. Its essential strengths relate to the possibilities to:

- Demonstrate workings and control of the system. This supports system understanding for both management and workers.
- Let users experience the proposed system. This may not only be important for training purposes, but also for building trust with respect to the quality of a solution.
- Involve users in determining job and worker characteristics that are relevant for selecting control decisions.
- Involve users in the construction of alternative rules for worker deployment.
- Contribute to team coordination and team building, by assigning appropriate roles.

Building on these strengths simulation games may also be a facilitator of continuous improvement. After all, opportunities for improvement are often highlighted as a natural consequence of gaming and the associated discussions. Note how this assumes game re-use.

Next to the meaning of simulation games for mastering new business concepts we considered the practice of game construction. More in particular we discussed the use of commercially available off-the shelf simulation packages (cots) as vehicles for gaming. We found that they may present a powerful basis for game design. However, one should be aware of a number of additional demands relative to a classic simulation model – that mainly addresses analysis. After all, for gaming user interaction is intrinsic. Specific demands relate to the modeling of: symbols used for representing real world entities, on-line indicators, decisions that are (not) allowed, and feedback on decisions. Further, to support learning, facilities for recording and analyzing decisions may be a welcome and necessary functionality.

Finally, we mention an interesting avenue for further research. In manufacturing simulation models workers are often modeled just like machines. Consequently, there is the real danger of omitting relevant human factors that influence worker and system performance. Bernard and Schilling (1997), and Baines et al. (2004) mention factors like ageing, and biorhythms. Other examples may include learning effects and motivation. Our experiences in game design and use made clear that gaming may help in determining relevant human factors and their settings. In turn these data may be fed into the simulation model to arrive at better quality outcomes. As made clear above, additional benefits may lie in an active user involvement. Obviously, quality of solutions and their acceptance may benefit from this.

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