PRE-INTRODUCTORY ANALYSIS OF THE SELECTED LEAN MANAGEMENT TOOLS IMPLEMENTATION EFFECTIVENESS USING SIMULATION ANALYSIS—CASE STUDY

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Abstract
The aim of the article was the lean tools implementation effectiveness analysis with simulation technologies based on a project in a selected manufacturing company. Production process analysis was based on qualitative and simulation analysis methods. The evaluation was supported with tools and techniques as the Value Stream Mapping, Fishbone diagram and 5 Whys. Simulation analysis was made on 3D models created within FlexSim simulation software. With the above elements, the evaluation of the Lean tools implementation effectiveness was done. Additionally, one prepared a collation of lean tools in the dimension of their capabilities to be simulated.

Keywords:
Lean management, VSM, Fishbone diagram, 5 Why, simulation.

1 INTRODUCTION
Among a number of managerial concepts, Lean Management, which directly derives from the Toyota Production System, has been the most often implemented one in recent years. The pace of the changes driven by the second decade of the twenty-first century force enterprises to redesign and reorganize internal processes to bring the highest consumer satisfaction with simultaneous high utilization of resources. In the concept of Lean enterprise, effective resource utilization is possible thanks to the identification and elimination of any wastes within the processes. From this perspective the wastes elimination is the key factor to improve the processes. In the case of Lean Management it can be said that the raise of process effectiveness is possible by „muda” eliminating and product quality improvement. Lean Management is interpreted as a set of tools and techniques for process improvement in the areas of productivity, material loss reduction, quality and safety. Lean is something more than a process slimming. Achieving the flexibility, which led the enterprise to respond to the dynamically changing environment without losing the fluency of current activities, is the desired state [1].

The concept is developed incessantly by connecting with other ones like Six Sigma which originally focuses on quality improvement by the elimination of defect root causes. The pair composes the concept of the Lean Six Sigma which comprehensively addresses the solutions to the problems related with efficiency, productivity and quality. It is not the only commonly known composition. Process modelling and simulating allow a better understanding of relations within processes and check the impact of changes made into virtual system. So the implementation of selected Lean Management tools and solutions can be preceded by simulation analysis to support decision making processes. Instead of interfering into the real system like Production line it can be done on the computer. The implementation of the lean tools and solutions is usually connected with the faith and experience of a responsible manager who has worked with lean before [2]. What is more, CAD and simulating tools can are very helpful at the stage of new line or hall designing. It allows to catch the potential constraints at a very early stage and gives a possibility to implement countermeasures.

The main objective of this article is to make an attempt to prove the effectiveness of selected Lean Management tools implementation supported by simulation analysis and classification of lean tools in terms of possibility to simulate and see their impact within simulation model.

The article is composed of 6 chapters. The first one is the introduction into the subject of the Lean Management and effectiveness verification method with simulation models. The next point presents the description of lean tools. Chapter 3 focuses on methods of the process analysis. The 4th point presents the case study made by authors which contains the description of qualitative and simulation analysis. The last 5th point is dedicated to summarizing and concluding the project.

2 SELECTED LEAN TOOLS DESCRIPTION
A lot of techniques and tools, which implementation improves the resource utilization effectiveness, build a whole Lean Management concept. For efficient process improvement it is crucial to know and understand the purpose and characteristics of selected techniques. Table 2.1 below presents the general information about lean tools with its objectives and their short description.

<table>
<thead>
<tr>
<th>Tool</th>
<th>Objective</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5S</td>
<td>Clean up and orderliness</td>
<td>Basic Lean Management tool with objectives focused on standardization and</td>
</tr>
<tr>
<td></td>
<td>maintenance</td>
<td>workplace maintenance in good condition.</td>
</tr>
<tr>
<td>Kanban</td>
<td>Work in progress stock</td>
<td>Tool designed for the production flow control with the Pull technique.</td>
</tr>
<tr>
<td></td>
<td>reduction</td>
<td>Production based on real consumers’ demand instead</td>
</tr>
<tr>
<td>Tool</td>
<td>Objective</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Kaizen</td>
<td>Process improvement</td>
<td>As a Lean tool understood as a philosophy of continuous improvement. The objective is to improve processes for cost quality and supply improvement.</td>
</tr>
<tr>
<td>Jidoka</td>
<td>Autonomy of units - reduction of deficiencies and failures</td>
<td>Understood as a automation is one of the main TPS pillars. This technique allows to stop production line at the moment of failure which permits to make production more efficient.</td>
</tr>
<tr>
<td>Poka Yoke</td>
<td>Failures elimination</td>
<td>Poka Yoke is a tool which is usually seen as a technical solution which prevents possible mistakes.</td>
</tr>
<tr>
<td>Andon</td>
<td>Signalling</td>
<td>A tool used for defects detection and process stoppage. It is about informing about the process variances or problems by a light-sound signal.</td>
</tr>
<tr>
<td>Just in time</td>
<td>Stock reduction</td>
<td>JIT is a production system consisting of the pull technique. The production process needs to be divided into phases to allow a rhythmic flow of the units. The stock should be placed between phases of the process. For effective functioning of JIT other tools like Kanban, SMED or continuous flow need to be present and active. The main objective is stock reduction.</td>
</tr>
<tr>
<td>SMED</td>
<td>Changeover time shortening</td>
<td>It is a set of techniques which objective is to reduce the time needed for changeover. Theoretically, the tool assumes maximal changeover time no longer than 10 minutes. The usage of SMED requires technical adaptation of the machines and changes within construction.</td>
</tr>
<tr>
<td>VSM</td>
<td>Process analysis</td>
<td>LM tool is used for qualitative process analysing and designing of the processes future states. The tool has its own graphic notation with a set of unique icons. VSM presents material flows and data interchange in a general way. It allows to notice the waste within processes. Current and Future State maps are built during working with VSM. The future state map includes all recommendations and solutions to make the whole process lean. It allows to redesign the process in a way which affects the numerical values related with productivity or for e.g. material losses KPIs analysed with quantitative methods.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tool</th>
<th>Objective</th>
<th>Description</th>
</tr>
</thead>
</table>
| Visual Management | Supporting operational management | Method used for presenting various states like:  
  - productivity,  
  - amount of production wastes  
  - machine inspection state,  
  - order fulfilment level,  
  - cleanliness standard  
Most commonly presented in the tables or LCD screens near working areas. |

3 SIMULATIONS AND SIMULATION MODELS
BUILDING METHODOLOGY

3.1 Simulation models
System simulations can be defined as a technique of problem solving by observations of dynamic model behaviour within time [9]. Production line models created for experimenting with changing variables like production cycles, production plan, number of changeover or hall layout is an element of simulation analysis and is part of the strategy which objective is to achieve optimum results in selected areas. Simulation is a strategy of achieving optimum results and the analysis should be based on 4 steps:

- Modelling – process mapping,
- Simulation,
- Analysis,
- Optimization [10].

To describe simulation analysis it is obligatory to explain the term of process modelling which is a significant part of it. Process modelling is a creation of formalized image which allows to analyse it (cohesion assessment, cost estimation) [10]. In contrast to the method of process modelling from the beginning of the 20th century like block diagrams, today's techniques are based on computer solutions which allow to build 3D objects and code their logic. As mentioned before, it is possible to experiment and look for optimal and suboptimal results on the finished model which represents whole Production lines or even hall. Simulation models are used when the number of variables is so large that solving the problem with analytical methods is excessively time-consuming which is most often in conditions of production system modelling [11]. In such situations it usually deals with discreet event simulations –‘DES’ which as J. Banks says is an imitation of the real system operations in time. DES has a specific approach of simulating processes in which the state of a system changes instantly at points in time as in the queue.
systems [12]. In learning a complex systems (complexity of
details and dynamic complexity), simulation by its ability to
manipulate space-time is the only tool allowing to capture
and understand the cause-effect relations over time and in
space, linked by multiple feedback (dynamic complexity)
[19]. According to Brian Hollock the benefits which come
from using DES in the context of production systems are
risk reduction, better process understanding, cost
optimization, lead time reduction and increase of customer
service level [12].
So if tools and techniques related to the simulation of
production processes are in place of optimization and
improvement, then it is reasonable to consider trying to use
them and link to Lean Management tools, which also
focuses on process improvements. Despite the fact that
most DES implementations and lean techniques are
separate, the tests of lean manufacturing assumptions on
simulation models have been already tested. R. Detty and
J. Yingling demonstrated through the simulation of discrete
events the quantified benefits related with the
implementation of the lean production approach. The
results of their work are presented in their article entitled:
*Quantifying benefits of conversion to lean manufacturing
with discrete event simulation: A case study* published in
T. Ohno defined seven types of waste called “muda”,
which are affected by phenomena such as variances and
load instability, also called “mura” and “muri” which is
excessive load. These 3 components form the so-called
3M model is a concern for most manufacturing plants.
Highly developed Lean organizations focus on eliminating
all three “M” from their environment, but most of them
focus first on eliminating muda because waste can be
detected by using simple tools and observations. In this
case, discrete event simulations tools are useful, which in
conditions of too high load allow for example, to identify
process bottlenecks and crew load over a longer period of
time. These theories and methods of improvement can be
interpreted as lean and DES are somehow complementary, while DES is supporting enterprise
decision-making [12].

3.2 Methodology
The construction of simulation models should be carried
out according to a specific methodology consisting of
several stages. Before working on a model, the problem,
which will be solved, should be defined. This will determine
the purpose of the simulation. At this stage, it is important
to set goals, also called success factors, to verify whether
the built model fulfils its purpose. The next step is building
a computer model in which simulations will be made. The
first work is to gather all the necessary data directly from
the modelled area or systems supporting the production.
Process mapping, for example, by VSM technique or
another simplified one such as OFD (object flow diagram),
enable understanding of the process flow. Finished
process maps are the source of data that are implemented
into objects in a computer model in the next step. The
advantage of today’s process simulation applications is
their compatibility with other applications such as MS
Office or the ability to read files in .dwg format. This
facilitates design work both at the model building stage and
at importing data from .slx files. The job of building the
model is to gradually expand it. Objects are given
appropriate characteristics so that they reflect the reality as
accurately as possible.
The third stage consists in validating and verifying the
created model, i.e. on the quality control of the built model.
Thanks to verification of the model, the modeller is able to
analyse the compatibility of the simulation model with the
assumptions. This allows to answer the question whether
the model correctly represents the logic and flows or not.
On the other hand, validation allows to establish the
conformity of the assumptions and vision of the modeller
with the real system [14]. Thus, the verification concerns
the correctness of the computer model’s functioning in
accordance with the assumptions, and validation refers to
the degree of accuracy of the real system [15] [16]. Such a
generated model should be built for a strictly defined
purpose because of which validation process should be
processed in this context [10]. The level of reality imitation
is a key factor in the system analysis and optimization. A
properly prepared model is a technical documentation, on
the basis of which there can be carried out a physical
project like relocation of equipment. Several methods of
validating simulation models are mentioned in the
literature:

- Comparing with other legitimate models containing the same elements that can be comparable
- Event validation by comparing events in the real system and model.
- Expertise of experts who know the modelled area and its specificity
- Analysis of historical data and comparing and using them to build a simulation model.

Design, conduct, and analysis of experiments on a
validated model is preceded by their design. The process
is about defining the initial conditions and specifying the
decision variables for which the waveforms are being
processed [10].
Experiments are performed for different values of the
decision variable to check the behaviour of the system.
The experiments are carried out in two ways:
- The deterministic method - one pass for the decision variable,
- The probabilistic method - variable values are randomized with statistical distribution.

In the case of probabilistic simulations it is recommended to
use statistical analysis tools to evaluate the obtained
results.

4 CASE STUDY
The analysis in this article is based on the activity of a
large food manufacturing company. The current annual
production volume in the company is about 45 thousand
tons of products with a market value of about 850 million
dollars.

4.1 Qualitative analysis of the production process
The qualitative analysis of the production process was
done by the Value Stream Mapping. The current and future
state map have been designed. The future state map
contains proposed improvements according to the Value
Stream Mapping methodology. The results of the process
mapping and proposed improvements are presented in
Table 4.1.1. The results of the implementation of the
proposed solutions in the context of lead time shortening
are given in Table 4.1.2. The next step in the qualitative
analysis was the creation of a cause-and-effect diagram -
Ishikawa, which identifies the source causes of the
selected problem. According to the problem solving
methodology the 5 Why’s method for the most probable
cause finds potential primary causes.
Table 4.1.1 Summary of identified sources of waste – VSM.

<table>
<thead>
<tr>
<th>No.</th>
<th>Identified problem</th>
<th>Proposed solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Excessive stockpile of blends at the mixer station - muda stocks, overproduction</td>
<td>Kanban system and Andon</td>
</tr>
<tr>
<td>2.</td>
<td>Ability to make mistakes when dispensing raw materials to the mixer - muda flaws</td>
<td>Poka Yoke</td>
</tr>
<tr>
<td>3.</td>
<td>Downtime in the transport of dough to the tray over the extruder - muda wait</td>
<td>Kaizen</td>
</tr>
<tr>
<td>4.</td>
<td>Excessive stockpile of intermediate in the production area - stock muda</td>
<td>Kanban</td>
</tr>
<tr>
<td>5.</td>
<td>Too long changeovers</td>
<td>SMED</td>
</tr>
</tbody>
</table>

Why is machine performance down?
- Because with higher speed of the sheeting machine there was an interruption of the dough web and the continuity of the process.

Why was the process interrupted?
- Because the dough was not extruded in the tray.

Why was the cake missing in the tray?
- Because at increased machine speed, the conveyors were operated in manual mode without stopping, causing the dough to accumulate and block in or in the tray.

Why was the cake cumulated and blocked in the tray or in the tray?
- Because it was sticking to the sides of the tray or conveyor, it did not reach the extruder.

Why did the dough stick to the sides of the tray or transporter?
- Because the structure of the tray and the transporter allows the dough to block, which exhibits adhesion (adherence) properties.

Table 4.1.2 Lead time before and after.

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead time</td>
<td>15.43</td>
<td>13.83</td>
<td>-10.37%</td>
</tr>
</tbody>
</table>

4.2 Simulation analysis of the production process

At the first stage of the work the basic objectives of the simulation project were defined:
- Problem definition - occurrence of waste in the production process
- Goal - reduce the waste of the production process

Within this stage, process efficiency measures are also defined, these are:
- Mixers utilization
- Transporters effective working time,
- Total production,
- The average condition (quantity) of the dough in the tray over the extruder.

The next stage is:
- Construction of the model reflecting current state – called AS IS
- Validation and verification of the model
- Construction of the future state model – called TO BE, along with the implementation of suggestions for improvements made during the creation of the future state map and analysis of 5 Why.

Table 4.2.1 Summary of results for selected KPIs in AS and TO BE models.

<table>
<thead>
<tr>
<th></th>
<th>AS IS</th>
<th>TO BE</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rising the transporters effective worktime by approximatel y 82% and downtime by 11% from 13.7 % to 24.9% and from 51% to 45.5%.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total production – 4300 kg</td>
<td>5943 kg</td>
<td>Productivity growth by 38%</td>
<td></td>
</tr>
<tr>
<td>Increase the use of mixers by about 36%. Reduction of changeover time by 83%.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase of the average amount of dough in the tray by 50%.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.2.1 shows the results for AS IS and TO BE models. As a result of the changes introduced after the VSM and 5 Why analysis, the increase in the speed of the sheeting machine and the change in the number of drums with small ingredients in the transport batch contributed to an increase in the effective working time, a drop in conveyor downtime and a reduction in stocks within the mixers area. In total, the increase of the working time of the conveyor was about 11 percentage points.

The increase in the effective working time of the mixers during one shift is mainly due to the change in the approach to the delivery of small ingredients and the shortening of changeover time. An additional factor was the acceleration of the sheeting machine from 65 to 68 sheets per minute as a result of Kaizen. The use of mixers increased by approximately 36%.

The increase in average tray over the extruder, which has increased by half, confirms the possibility of increasing the speed of the sheeting machine without the risk of discontinuing the process and breaking of the dough web. The authors are aware of the fact that increasing the tray over the extruder does not significantly affect the efficiency of the machine but, as evidenced by the 5 Why analysis, changing the structure of the conveyor and the cartridge can reduce the risk of dough blocking and discontinuity of the process.

It was decided to analyse the discussed and implemented lean tools in the context of whether or not they can be simulated using the models. Table 4.2.2 below shows the
compilation of several tools with their simulated category and short commentary.

Table 4.2.2 Classification of lean tools in the context of their ability to simulate.

<table>
<thead>
<tr>
<th>Lean Tool</th>
<th>Category</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andon</td>
<td>Non-simulative</td>
<td>It is a supportive element that does not affect the measurable values for e.g. Efficiency.</td>
</tr>
<tr>
<td>Poka Yoke</td>
<td>Simulative</td>
<td>It is possible to simulate errors or breakdowns of statistical distribution and notice the differences.</td>
</tr>
<tr>
<td>Kaizen</td>
<td>Simulative</td>
<td>It is possible to simulate changes as a result of projects that improve Kaizen.</td>
</tr>
<tr>
<td>Kanban</td>
<td>Simulative</td>
<td>It is possible to simulate changes due to the introduction of a Kanban by observing a drop in inventories near production lines.</td>
</tr>
<tr>
<td>SMED</td>
<td>Simulative</td>
<td>It is possible to simulate a change in time due to SMED techniques by shortening the changeovers (idle) time of machines.</td>
</tr>
<tr>
<td>5S</td>
<td>Non - simulative</td>
<td>There are no quantifiable observations of 5S.</td>
</tr>
<tr>
<td>Ishikawa diagram</td>
<td>Non- simulative</td>
<td>This is a trouble-shooter, a problem solving tool - element of qualitative analysis. Ishikawa's scheme is unimaginative. It is possible to check results of the chosen solution of the actual problem using the simulation technology but only in selected cases.</td>
</tr>
</tbody>
</table>

Thanks to the mapping of the current system and the implementation of improvements proposed in the VSM process, the authors could verify their effectiveness. The results of the implementation of selected lean techniques are presented in the summary table and improvement was observed in all selected areas. A set of lean tools was also prepared and classified according to the criterion of their ability to simulate.

Despite the fact that many techniques have simulative features, and both methodologies are complementary, the vast majority of projects in business conditions are isolated from each other. This is mainly due to the too low level of management staff awareness and small number of specialists in the labour market who have the proper knowledge and skills.

Thanks to its features, simulation analysis is certainly a tool that supports decision-making related to the reorganization or improvement of production systems. The use of both types of analysis i.e. qualitative and simulation in the improvement process is justified and beneficial. It allows to determine the effect of changes at the design stage, which may speed up the decision-making processes and as a result, increase the competitiveness of enterprises on the market. The development of this field in the local market is noticeable. This proves the scientific and technological advancement of both research units and enterprises awareness.

6 REFERENCES

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5 CONCLUSIONS

Due to the multitude of relations in the production systems, the assessment of the lean tools implementation effectiveness is not an easy task because of its ambiguity. Lean management gives a number of techniques and methods that will surely improve the manufacturing processes as evidenced by the above examples and numerous references. The above article is about improving processes using lean production techniques combined with simulation analysis. Through their combination, it is possible to see how the lean implementation actually affects the efficiency of production systems. It was found that the lean target and DES simulation analysis are consistent and can be seen as complementary.


