Lean manufacturing

Productivity increase in a large size slaughterhouse: a simulation approach applying lean manufacturing

Carlos Coutinho Fernandes Junior
Federal University of Santa Catarina, Florianópolis, Brazil, and
Leonel Teixeira Pinto
Department of Chemical Engineering and Food Engineering, Federal University of Santa Catarina, Florianópolis, Brazil

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Abstract

Purpose – The main purpose of this paper is to develop a study of the determination of the most appropriate execution steps, necessary for the construction of modelling, simulation and optimization for the specific area of slaughter line balancing. And through the developed model to demonstrate the application of simulation to increase productivity in a large-size swine slaughterhouse, focusing on operator stations balancing. The built model may be applied to support the management of the plant, allowing to evaluate and decide the optimized scenario that meets current needs considering operational cost, production demand and productivity.

Design/methodology/approach – For the research development, the selected software supports the characteristics of the evaluated process, in this case, a discreet simulation with stochastics variables. The studied plant was modelled door by door, from the swine reception until the packaging area. The research methodology was based on lean manufacturing (LM) principles, particularly in workstations balancing, by optimizing the idle time of the operators, comparing with the cycle time of each task, in the evaluated workstations.

Findings – The achieved result with the modelling and simulation was the increase of 11.89% in plant productivity through manpower optimization. The study indicates that the simulation applied with LM concepts as operative stations balancing and value stream map can be a very useful tool to support decision-making for productivity improvement.

Originality/value – This study approaches how modelling and simulation can support decision-making to implement improvements associated to workforce balancing optimization, especially in the studied area (agribusiness, animal slaughter). The studied process presents great variability associated with the processing time of each phase, making the analysis and modelling more complex. The number of workstations involved, with more than 800 employees, is an important point in the research, considering that cases with higher values than the case presented were not identified in literature.

Keywords Decision-making, Productivity, Lean manufacturing, Balancing workforce, Modeling and simulation

Paper type Research paper

1. Introduction

In the current literature, many studies are found considering the theme of productivity and process costs, where the main objectives are the reduction of waste as a way to increase the organization's competitiveness (Pacheco *et al.*, 2015). Within this approach, lean manufacturing (LM) is a well-known philosophy, which originated from the Toyota

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Production System (TPS) and directly aids waste reduction through important tools such as value stream mapping and workforce balancing of the process. These techniques are good alternatives to optimize existing resources before investing in new technologies.

By improving processes, a business can increase its internal efficiency, effectiveness, productivity and customer service levels (Kumar and Phrommathed, 2006). In a more classical definition, productivity can be defined as the relation between what occurs in the system and what is produced, or more simply, the ratio between output and input. The measurement of productivity is a measure of a physical phenomenon, such as the transformation of energy into work, and not a measure of money or other substitutes (Misterek *et al.*, 1992).

LM philosophy has been applied in multiple segments (Sreedharan and Raju, 2016), including application examples in agribusiness and food area (Noorwali, 2013; Besseris, 2014; Satolo *et al.*, 2017). To guarantee the customer demands, by minimizing of wastes, is the main basis of LM (Bhamu and Singh, 2014).

An important issue to be considered is that LM leads to important changes in the process that can face difficulties to implement, due to a natural resistance to change the current company culture. It is not easy for the manager to make a decision when all the benefits or possible risks are not quite clear. The decision-making is defined as the process of arriving at a choice in face of competing alternatives. But it is not easy to decide the final best solution. Individuals tend to make suboptimal decisions under pressure and uncertain situations (Peteros and Maleyeff, 2015).

Until the past decade, simulation was considered to be more suitable for well-defined scope research work than for daily decision-making or any other use (Greasley, 2004). Nowadays, there are examples of models that are used as a great tool to validate a better process configuration that leads to increased efficiency within a current routine manufacturing scenario as approached by Standridge and Marvel, 2006; Shaaban *et al.*, 2013 and Da Silva *et al.*, 2014).

Simulation can also be used as a great support for understanding ergonomic constraints at the work stations, contributing to an alignment between conditions that improve human work and its adaptation to the operating resources (equipment, layout, etc.) optimizing the whole process (Neumann and Dull, 2010).

This research project, whose studied area is the agribusiness, more specifically, the swine slaughtering, has an inherent complexity that is related to the number workstations (In the applied example were more thadifferent 800 workstations modelled).[AQ] The living animal is slaughtered and separated in several parts. This process of high variability (Callel, 2016), which is divided into different productive flows, which makes the analysis complex. In this kind of process, there is a great opportunity to apply LM concepts considering the flow optimization of the whole line (including labor, machinery efficiency and inventory) and the variability of cycle time in the workstations. In this case, the value stream map (VSM) methodology, that is an improvement tool to assist in visualizing the entire production process, representing both material and information flow (Rother and Shook, 1999), can be applied in the whole plant to identify the main opportunities that can lead to a productivity increase. Even with all the information added in VSM, depending on the plant size, without using the resource of a modeling software, the implementation of the potential improvement is uncertain and complex.

Based on challenges and opportunities initially raised, the main research objective is to develop the necessary study in the improvement of the determination of the necessary steps for the construction of the modeling and simulation and optimization for productivity improvement in an appropriate way for the specifics of the balancing of slaughter lines. The methodology of this research is referenced in the principles of LM, in specially in the reduction of the idle time of operators in the workstations, through balancing each operative post in whole production line. To meet this research scope, was chosen the software that best meets the assumptions and applications for the process profile under study. For this analysis, the conditions applicable in the production process of a slaughter plant need to be considered, such as equipment of different capacities and requirements required by Brazilian legislation (e.g. mandatory breaks due to low temperature exposure).

2. Literature review

2.1 Lean manufacturing as continuous improvement strategy

LM has been adopted by the industry as a response to the need to focus on customer demands without additional resource requirements, which would add them cost (Bhamu and Singh, 2014). The term "Lean" was originated from the book "The Machine that Changed the World" by Womack *et al.* (1992), that is directly linked to the TPS. TPS is a manufacturing management philosophy that emerged in Japan in the mid-1960s, being the basic idea and development being credited to the Toyota Motor Company. The main concepts developed in Toyota was created by the vice president of the company, Ohno (1997), and these practices were more studied in the 90's decade (Womack *et al.*, 1992). The main principles of LM are described and based in a value-driven process view, problem-solving and long-term thinking (Liker, 2004) which can be described into practices focussed on waste reducing.

Considering LM concepts implementation, each company must evaluate which practices are important and useful for continuous improvement strategy. At this point, it is very important to understand the essence of the LM objective: to reduce waste in human effort, inventory, time to market and manufacturing space to become highly responsive to customer demand while producing quality products in the most efficient and economical manner (Singh *et al.*, 2010).

Considering, especially human effort, time to market and effort inventory, they are very connected to the studied theme of this research. A way to identify opportunities in these components is to use VSM methodology. The VSM objective is to identify all types of waste in the value stream and to take steps to eliminate them (Rother and Shook, 1999). Many researches were conducted exploring VSM application in the factory floor flow (Jasti and Sharma, 2014; Basu and Dan, 2014). Considering the main costs of production process, work force is one that has more impact. But LM tools implementation is far from problem-free and companies may experience difficulties in sustaining definitive success (Gaiardelli, *et al.*, 2019). It is important to understand to what extent human factors, are affected by the implementation of both hard (defined as technical and analytical tools) and soft (concerning people and relations) LM practices. Leadership learning has a key role in achieving long-term superior performance.

2.2 Workforce balancing

One of the biggest costs in any industrial operation is the labor cost of the process. To optimize manpower and achieve proper balancing, an essential step in determining balance is the time analysis of operator activities. With this analysis it is possible to determine the variability in operator activities that can generate an oscillation in the production flow

and consequently, stock accumulation in some stages of the process. By analyzing work elements, it is possible to know the cycle time of each process within the assembly. To perform line balancing it is necessary to calculate the line takt time. The takt time is the pace of demand, that is, the rate at which a company needs to produce a product to meet customer demand. The takt time is calculated as:

$$\textit{Takt time} = [\textit{actual production time per shift}/\textit{customer demand per shift}] \quad (1)$$

It is important to highlight the concept of cycle time: It is the time from the start of an operation until the operation is completed. It's the processing time of a product. It is very important to relate cycle time and takt time (Rother and Harris, 2002). If the cycle time is much shorter than the takt time, overproduction occurs, because the line is balanced to produce more product than is needed to meet demand (Kumar, *et al.*, 2018).When all cycle times are known, the next step is to analyse activities that interrupt the flow and are classified as waste.

One of the great strategies for process rationalization is the optimization of operating stations, evaluating the distribution of tasks in each operating station. The purpose of balancing is the workload equilibrium between operators, so that the cycle time at each workstation does not exceed the production takt time, creating a continuous flow without stock accumulation.

2.3 Modeling and simulation as support for decision-making

In a classical concept (Pegden *et al.*, 1990), simulation is the process of assembling a computational model of a real system and conducting experiments using this model for the purpose of understanding its behaviour and/or evaluating strategies for its operation. Simulation is used to evaluate complex systems, supporting the find of solutions related to the physical configuration or operation rules of a system. Their applications have grown in all areas, supporting managers in the decision-making process, providing a better understanding of processes behaviour and its variables (Sakurada and Miyake, 2009; Frazzon *et al.*, 2017). In processes that are concentrated in manual labor, the model built by simulation is able to optimize the allocation of each workstation to achieve a better overall balance of the line and consequently optimize the necessary number of operators. In this case, the simulation assists in the clear identification of the points of the processes where must be focused on reducing variability and stabilize the total process cycle time (Shaaban, *et al.*, 2013). Simulation contributes to solve questions in assembly lines that are affected by the impact from the operating times variation in function of the variability of the operation itself, increasing total production average time (Biman *et al.*, 2010).

To formulate the process simulation, it is necessary to follow a sequence of steps (Banks *et al.*, 2005):

- Formulation of the problem;
- Formulation of objectives;
- Data collecting;
- Modeling and coding;
- Verification and validation of the model;
- Experimentation and analysis;
- Documentation and recommendations.

An important issue to be evaluated is the justification for using simulation in LM (Mor *et al.*, 2016) projects. LM concepts can be used highlighting opportunities in the process to eliminate waste in the stages of the production line, and simulation is used to help evaluating potential gains and generate more confidence in decision-making (Standridge and Marvel, 2006).

Balancing the sequential stages of a complex production process is one of the most important responses to be expected when applying and developing a discreet simulation project. In literature, there is a large number of researches on line balance project in series production systems, focused on ensuring that lines can be projected in such a way that the allocation of the workstations may be distributed on a regular basis (Rajakumar *et al.*, 2005; Scholl and Becker, 2006; Zeng *et al.*, 2012). The purpose of such balance is to maximize the result, using less space and keeping a little inventory as possible on the line. It is desirable that process managers have a systemic view of the effects and changes, but also be possible evaluate important changes in specific points of the process. In this context, simulation can be used to optimize the process layout and other available resources to obtain the best line configuration balancing, generating this systemic vision to support decision-making for better (Da Silva *et al.*, 2014) cycle times and the total processing time more competitive.

3. Methodology

The project was conducted as an applied research which aims to generate knowledge for practical application, focused on the solution of a real problem. From the point of view of technical procedures, the research is classified as action research because it is carried out in association with the resolution of a problem, in which the researcher interferes in the object of study in a cooperative way with the participants of the action, seeking to solve a formulated problem (Turrioni and Mello, 2010). The action-research methodology aims to gather information about the problem, feeding the research with the theoretical knowledge previous to the practice and to describe the processes and generalizations to generate results (Thiollent, 2005).

To develop the initial part of the research, the construction of the initial plant model, the software Flex Sim® was chosen considering the project demands and the main principles of VSM (Ehrlich, 2002):

- To allow to identify opportunities in each phase of the process: layout fit out, stock accumulation, occupation rate per workstations, and make the connections that provide a global vision of the whole process opportunities.
- To provide security for decision-making to save time and reduce monetary investment.
- To help with the resources allocation and barriers prevention to attend the work focus: the productivity improvement and correct scaling of the team.

The plant modeling and simulation followed the methodology adapted from Banks *et al.* (2005): formulation of the problem and objectives, data collecting, modeling codification, verification and validation.

3.1 Formulation of the problem, objectives and data collecting

The problem formulation is important to understand its scope and to give the direction to reach the main project objective. For the case of this research project: To optimize the resources in the productive process of slaughtering, getting an improvement in the Man hour/ton performance indicator, equalizing the factors idleness, and legislative demands, like obligatory breaks, due to the plant thermal condition.

Aiming to acquire the data, the factory was divided in two large areas: slaughter and cut area. The operation time of each workstation was collected by a statistically planned number to be reliable and to evaluate the variability. Table 1 illustrates the data collected for the construction of the initial model to represent the current operation state of the plant.

Table 1 highlights data used to build the initial version of the model, creating the plant real flow with speed and occupancy rate of each workstation. An important issue to be considered about data from Table 1 is the production plan, that is the volume of production planned for the plant, that informs daily amount of slaughtered and product mix in the area of cuts. This information is important, considering the concept of Reprogramming Manufacturing Systems (RMS), where production needs to be simulated considering changes in the mix and in demand for a reproduction that is closest to the real situation (Garbie, 2014). A manufacturing process, even handling a small variety of components, may be very different, depending on inputs (Gerwin, 2005), which leads to different processing cycles in tasks. A decision for this work was to measure the cycle times of products historically with higher manufacturing volume.

Figure 1 shows the micro chart of the plant: Slaughter and cut area. In the flowchart is presented the phases of the process, that was modelled.

Table 2 presents the indicators (just one fraction of the data is demonstrated in Table 2) that were calculated from the initial data presented in Table 1. It is important to define the main elements in Table 2:

- Number of operators per shift: number of operators needed to execute the tasks considering the present takt time, which depends on the current production plan. In some workstations, the operator number is less than one, what validates the idea that the employee who works in that station is, partly, idle.
- Cycle time: interval between each piece that passes in the workstation. Different Cycles between stations may mean possible balance optimization opportunity between workstations.
- Distribution: traditional line balancing methods assume that the operating times at each station are fixed or determinate. This assumption is not realistic, since times are random variables (Nkasu and Leung, 1995). The program Flex Sim® generates characteristic distribution to each workstation, based on the data of the specific station. This represents the variation of each specific operative station. This calculation mode increases the model accuracy when compared to the use of an estimative of the average distribution. If none of the distribution suggested by the model provides an adequate fit, an empirical distribution is constructed. In both cases, the selected distribution can be represented in the choice of the simulation software analyst.

Table 1. Data collected for the initial model

Input	Goal
Layout CAD – Whole plant	To formulate model based on actual layout
Production capacity by area	To identify different capacities by areas (bottlenecks)
Shift operation time	To know actual operation time per shift
Planned stop over times	To identify possible points of product accumulation and optimization opportunities
Operators by area and shift	To understand current distribution of operators by area
Time for each operator to execute a task	To know the time variation of each operative station by employee (minimum of 10-time measures per employee)
Production plan	To compare de current demand and plant capacity

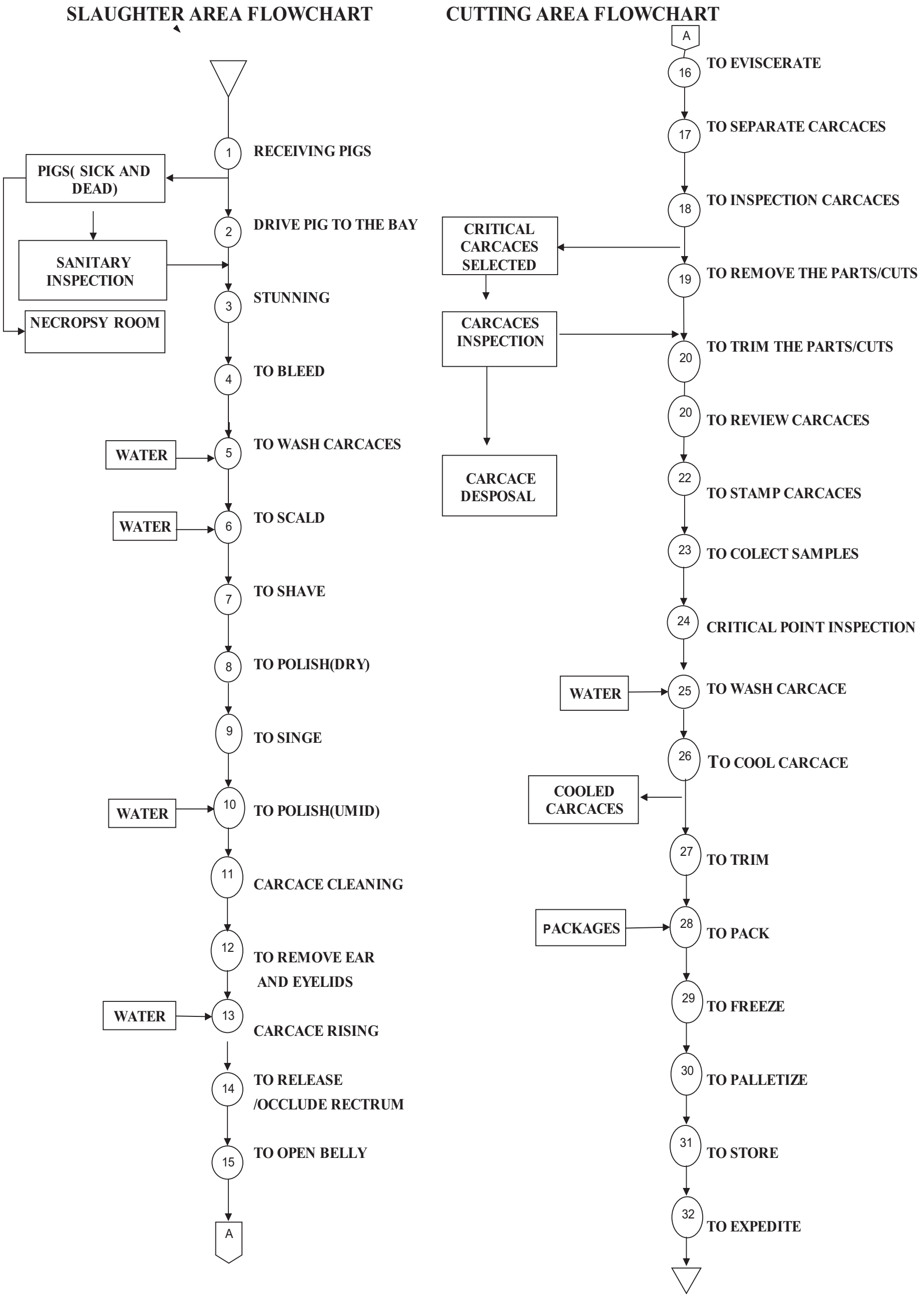

Figure 1.
Slaughter and cutting area flowchart

Tasks	Time for 1 piece	Production plan (pieces per hour)	Pieces/minute	Pieces/hour	Operators/shift	Average	Frequency	Cycle	Min./Piece	Statistical distribution
Unload truck	*0.11*	*450*	*8.71*	*523*	*0.86*	*475.00*	*0.01*	*0.10*	*0.11*	*Beta*
Tattoo pig (identify)	*0.03*	*450*	*31.36*	*1881*	*0.24*	*8.25*	*0.20*	*0.03*	*0.03*	*Exponential*
Bring the pig till entrance	*0.05*	*450*	*20.38*	*1223*	*0.37*	*101.50*	*0.03*	*0.04*	*0.05*	*Exponential*
Lead to stunning	*0.23*	*450*	*4.42*	*265*	*1.70*	*410.01*	*0.03*	*0.20*	*0.23*	*Erlang*
Put the chain on pig foot	*0.13*	*450*	*7.57*	*454*	*0.99*	*6.83*	*1.00*	*0.11*	*0.13*	*Johnson bounded*
Hang the pig	*0.05*	*450*	*18.46*	*1,108*	*0.41*	*2.80*	*1.00*	*0.05*	*0.05*	*Exponential*

Table 2.
KPIS generated by the model based on the initial collected data

3.2 Modeling codification, verification and validation

The built model reproduced the present layout limitation of the real plant, using all the previously mentioned data, and represents the factory in operation since the first step, swine reception, until the expedition of the final product. Starting from this initial model, it is possible to make the optimization simulations for the Man-hour/ton indicator.

To draw conclusions about the consistency of the initial model and make valid inferences, the simulations were systematically repeated, to have consistency on results. This validation is very important, since it guarantees the consistency of the following steps of the research project and tests the product flow throughout the process: Swine entrance, entry and exit of the carcasses in the cold room and entry and exit of the main cut lines.

It was also realized the validation of the total process flow with the plant technical team, aiming to confirm that all the process flows are at the same order as they are executed in the real situation. Another validation conducted was the verification of the sampling of the time cycle times of the tasks. With this information, a replication of the process was performed within the simulator, using 10 replications of each task time, which reached a stable median. The median is the value that each parameter achieves within replications and this value is compared to the production history, and validation is accepted if these percentages do not exceed 2% variation, which would be the acceptable limit for such a process.

The actual production time per shift is equal to the time from start to end of the shift, without considering the scheduled breaks and lunch. The cycle time of the slower operation is equal to the part rate that is produced by the line, that is, the operation with the longest line cycle time directly affects productivity. To perform the line balancing it is necessary to know the takt time of the line.

$$Takt\ time = actual\ production\ time\ per\ shift / customer\ demand\ per\ shift \tag{2}$$

For example, for the operative post presented in Figure 2, the takt time is calculated by:

$$Takt\ time = (7,3\ hours'/shift\ x\ 60\ min\ x\ 60\ sec)/1408\ carcasses/operator \tag{3}$$

With the initial model built, that represents the plant current operation, the balancing of workstations is executed. Based on occupancy rate of each workstation, the balancing is done step by step of the process, using the concept known as "workstations operational

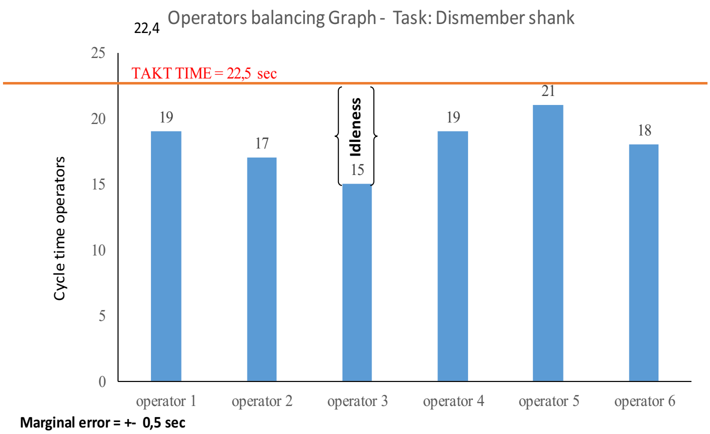

Figure 2.
Task "Dismember shank" operator balancing graph

balancing", that is a known LM practice, comparing total available time of each operator in their work shift with total necessary time to process the product volume that is passing by the line. This total time is based on the minimum standard time for a piece be processed in the workstation. In Figure 2, example of a task, it is observed the time, measured in seconds, that each operator (represented in the column) spends to execute the task "to dismember shank". The horizontal line represents the takt time of the production line.

In Figure 2, in this workstation, a shank must be dismembered by the operator on maximum time of 22.5 s (takt time), to avoid product accumulation. In this example, all the operators dismember one shank in less than the 22.5 s cycle (no bar exceeds the takt time, i.e. 22.5 s), confirming some idleness in this workstation. If summed the time of all operators to do the work (columns), divided by the cycle time, it is obtained the necessary number of operators to the present workstation, that in this case are about 5.

Example Figure 2:

$$Total\ time\ operators\ cycle\ time / Takt\ time = Number\ of\ operators\ needed\ to\ do\ the\ task \tag{4}$$

$$(19 + 17 + 15 + 19 + 21 + 18)/22,5 = 4,8 \tag{5}$$

However, there are 6 operators in the workstation, according to Figure 2. So, there is an extra operator that, if removed, it won't result in production flow delay. The opposite situation could also occur if the cycle time of one or more operators exceeded the takt time. This means that over time there would be an accumulation of product, as the time required for each operator to do the task is greater than the product flow on the line (determined by takt time), requiring more operators for balancing the production line.

With the support of the initial model, 100% of the workstations were analysed based on the concept described above, and it was obtained the occupation rate of each operator in the whole production line.

In Table 3, the analysis results are shown (only a part of the more than 800 analysed workstations), in special the diagnosis of part of the cutting area, where was obtained the biggest difference between current operator number and the necessary projected by the model to process the planned production volume, according to takt time.

To calculate the current occupation rate in each workstation, the model ran several interactions. The occupation rate is the percentage of the total time available that each operator is using to do the task in his operative post. For example, if the occupancy rate of a task is 67%, means that there is 33% of idle time that should be used to do anything else.

The opportunity to remove operators per workstation was analysed, considering not to exceed the occupation rate in more than 90%, to avoid ergonomics problems. In Table 3 it is observed variation in the occupation rate, indicating real opportunities to reduce the number of operators.

The final idleness analysis result and the workstations balancing, show a significant difference of 74 employees comparing to the current number and the optimized situation considering the assumption of not affect the current production volume.

Table 4 presents the total number of operators per area, to which the program identified reduction opportunity.

4. Results

The opportunity identified by the model was evaluated and validated by the technical team of the plant. Then, the gradual removal of the surplus operators of the

Operative post	Occupancy rate (%)
To weigh filet	34.00
To pack filet	37.00
To pack skin	32.00
To pack belly and rib	67.00
To clip on filet	37.00
To take out bone	32.20
To pass trimmer machine in ham	41.00
To trim silverside muscle	47.50
To trim topside	42.70
To trim knuckle	34.00
To trim shoulder and fat	72.00
To trim chop	29.00
To trim loin	38.10
To bone shoulder	44.84
To bone ham	59.62
To cut ham	51.38

Table 3. Tasks occupancy rate

Area	Actual operators no. (2 shifts)	Necessary operators no. calculated by modelling (2 shifts)	Difference
Swine reception	70	70	0
Slaughter	105	102	2
Cutting area	630	558	72
Total	805	731	74

Table 4. Current operators number vs proposed by modelling

workstations was done. This job was monitored by ergonomics and safety at work team, to guarantee that the remaining operators would not have any kind of repetitive effort injury. From the 74 positions raised as opportunity, 52 were validated by the safety at work team.

Table 5 presents the activities with the referred number of employees reduced and the occupancy rate comparison, before and after the balancing process and operators removal. It is observed that, after the balancing, the average occupation rate, in these activities increased from 43.71% to 71.56%, (Table 5). This table shows the essence of the modeling and optimization, based on LM principles, to reduce waste resources that do not give value to customer what lead to have a better resource management (Gibbons *et al.*, 2012). Operators were removed in workstations where before, according to initial diagnosis, there were idleness. The idle time was reduced to produce more pieces/minute/operator, keeping the premise of not exposing the remaining operators to ergonomic risk and not generate bottlenecks in any of the adjusted activities.

The occupation rates after optimization are not levelled (Table 5), showing differences between activities, because, depending on the activity complexity level, it is not recommended that the occupancy rate has high values, considering the ergonomic risk, for example, high weight pieces, which the operator handles. So, in this case, it is used the following assumption: the average occupation rate after the balancing cannot exceed 90%, to avoid excessive fatigue or stock accumulation.

Table 5.
Activities occupancy rate before and after balancing the number of operators (two shifts)

Operative place	No. of operators before optimization	Occupancy rate (%) before optimization	No. of operators after optimization	Occupancy rate (%) after optimization	Operators reduction after optimization (2 shifts)
To weigh filet	4	34.00	2	78.88	2
To pack filet	4	37.00	2	85.84	2
To pack skin	4	32.00	2	74.24	2
To pack belly and rib	16	67.00	14	88.82	2
To clip on filet	4	37.00	2	85.84	2
To take out bone	6	32.20	4	56.03	2
To pass trimmer machine in ham	16	41.00	12	63.41	4
To trim silverside muscle	32	47.50	28	62.97	4
To trim topside	28	42.70	24	57.79	4
To trim knuckle	20	34.00	14	56.34	6
To trim shoulder and fat	84	72.00	80	87.70	4
To trim chop	12	29.00	8	50.46	4
To trim loin	4	38.10	2	88.39	2
To bone shoulder	34	44.84	30	58.95	4
To bone ham	36	59.62	32	77.80	4
To cut ham	24	51.38	20	71.52	4
Total (two shifts)	328	43.71	276	71.56	52

The optimization was executed with the gradual removal of 52 employees in workstations (Table 5). This action was evaluated for three months, period in which was monitored the production volume indicator, to identify a possible retraction.

In Figures 3 and 4, it is presented productivity indicator Man-hour/ton after operator removals in the workstation.

As the Man-hour/ton indicator is calculated by dividing the total hours worked per month by the total monthly volume of product, the withdrawal of 52 workers had a direct effect on the total monthly hours, with a consequent reduction of the Man-hour/ton indicator. This value was kept in the following months after the manpower reduction (52 operators). But it is also expected that the historical volume produced must be maintained. Figure 3 shows the behaviour of the worked hours and of the produced volume, during the same

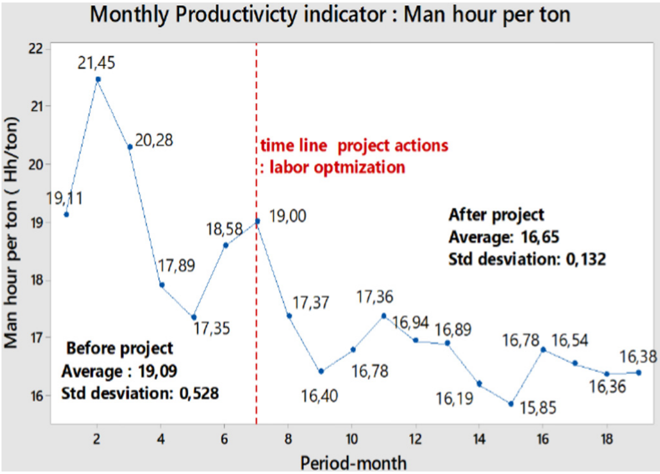

Figure 3.
Evolution kpi Man hour per ton

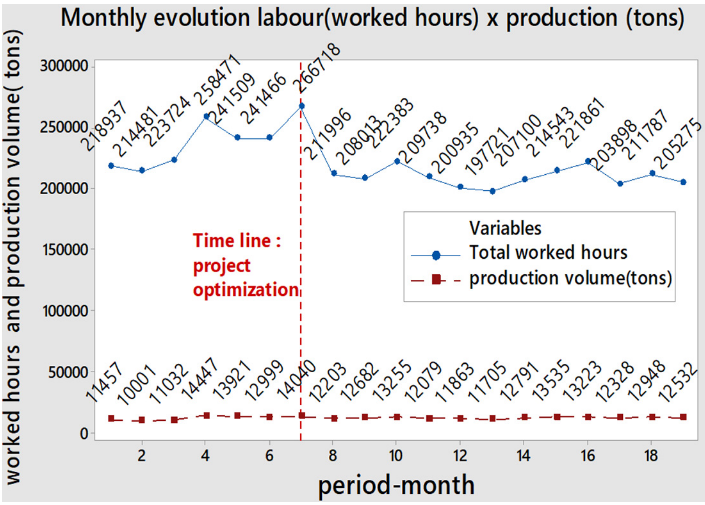

Figure 4.
Worked hours (labor) × volume production (tons)

period of the previous graph. Through Figure 4 analysis, it is observed that the improvement of the Man-hour/ton indicator matches the period when it had the reduction in hours, in function of the removal of the workers.

Table 6 presents a summary of the main indicators, before and after workers removal. With data from the 12-month verification period, after the optimization of the operating stations, it was evaluated that the reduction in Hh/ton presented an average reduction of 11.89%. To verify the variation and error associated with this mean, the statistical tool "Test *t* for a sample" was used, which calculates a confidence interval for this mean value. The confidence interval obtained was that the mean reduction value is between 10, 62% and 14.90%, with a confidence level of 99%. Considering the historical value of the last 10 years of the studied company, it was the best reduction result obtained, superior to the goal established in the strategic plan which was 8% reduction. No reduction values greater than 10% were found in literature, considering the number of operative posts involved.

The worked hours in this period reduced in 10.17% and the production volume maintained stable with a small raise of 1%. The plant continued to produce the same volume, realizing less 10% of worked hours. The positive effects are higher productivity and significant cost reduction.

Figure 5 presents a linear regression graph between the Man-hour/ton and the worked hours, covering the period before and after the operative posts removal, to definitely stablish the direct impact of the reduction of worked hours, due to the operative posts reduction.

The R coefficient adjusted of 96.2% demonstrates a strong correlation between the worked hours variation vs the Man-hour/ton indicator, in extended period of one year, which includes the project execution period, expressing each graph point per quarter (Table 7). The two first points of the graphic are exactly the two quarters after the action's execution, presenting a reduction/stabilization of the worked hours, due to the operative posts removal executed in the project, reducing Man-hour/ton kpi significantly.

This improvement with the operative posts removal was only possible due to occupation rate optimization in the workstations, shown in Table 5, raising the number of pieces per workers/minute in a safety level, without remaining operators wear or stock accumulation.

These results confirm the wide application of process modeling focused on large slaughtering plants (more than 800 employees) related to the optimization of the employed manpower, with a larger number of modelled workstations, when comparing with other researches mentioned in literature (Pereira and da Costa, 2012).

4.1 Sizing of obligatory pauses

Another important application of the model is the possibility to size the necessary resources to meet legal demands from local Ministry of Labor and Employment. Some of them are related to the exposition to low temperatures (below 12°C), that is a feature of this kind of process (slaughter). For the worked period (8.48 h per shift), the pause is 60 min, which, in the existing framework of two shifts, it is equivalent to 120 min of obligatory pause per day. Evaluating the options, in this case it can be performed in two ways:

Table 6.
Kpis before and after operators removal

Indicators (Kpis)	Before optimization	After optimization	Difference [(Average) %]	Confidence interval (99%)
Man-hour (Total labor)/Ton-Whole Plant	19.09	16.82	−11.89	10.62-14.90
Man-hour (Total labor)	237,901	213,702	−10.17	–
Production (tons)	12,577	12,713	1.08	–

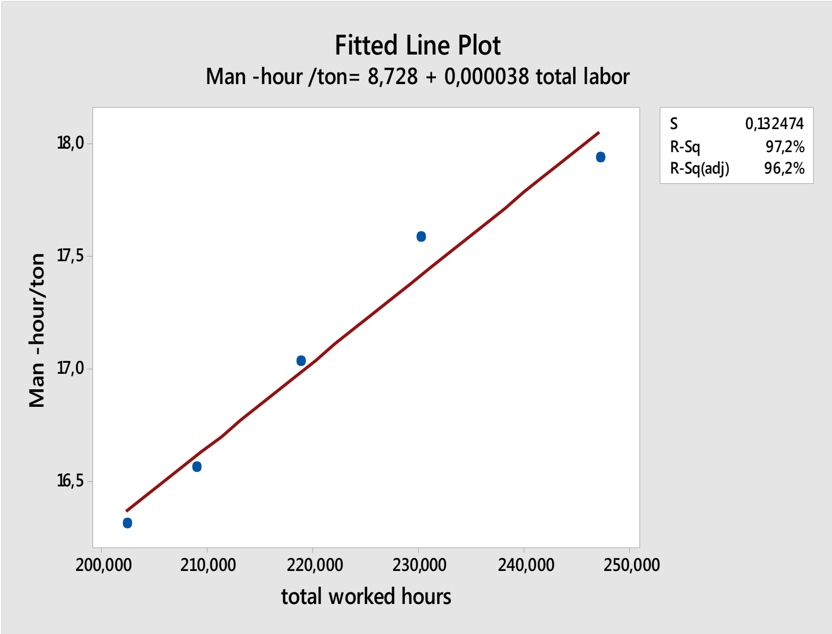

Figure 5. Simple linear regression: man hour per ton × total worked hours

Table 7. Man hour/ton × total labor

Period	Man-hour/ton	Total labor (hours)	Observations
Quarter 1	17.94	247,179	period before the labor optimization
Quarter 2	17.59	230,098	
Quarter 3	17.03	218,720	period when were taken out 52 operators
Quarter 4	16.31	202,200	period after labor optimization
Quarter 5	16.56	208,902	

- To stop all the production during pauses, reducing the production capacity in 1 hour, what represents an 11.4% reduction of the available time per shift.
- To stablish a replacement system during the breaks, not to stop the production, in the clear condition that 100% of the employees have the break time respected. To execute this step, it is a necessary to increase the team, in order to have enough operators working in the workstations while part of them are taking the pause.

Both options affect negatively the indicator Man-hour/ton and the final cost of the process. In the first option, there is reduction of the daily production volume, and the second option needs a bigger number of employees per area.

This analysis is not simple, and, in this case, the model in Flex Sim®, built for the plant, is used to do an evaluation, where must be included the following indicators analysis:

- production volume per shift;
- final amount of employees; and
- indicator Man-hour/ton.

This analysis, with acceptable parameters of precision, is only possible with the built model support, considering the great number of operative posts involved (more than 800). It is necessary to resize the minimum number of operators needed per area to keep the line working during the breaks, without causing idleness besides the break time. An important impact is that the workers must have skill on the specific position where they will be working substituting the other workers. The number of needed extra employees is related with the number of different positions that they will be able to substitute.

Before running simulation with the program Flex Sim®, to choose scenarios to be tested, some basic assumptions must be considered:

- Production forecast: to evaluate the demand over the coming months and the last two years historical. If the demand is from 15% to 20% below the current capacity of the plant, it is not necessary to increase the team to work during the pause. The best solution can be to stop all the line during the pauses.
- Capacities per area: the process is divided into three parts: animal slaughter, cut area and final packing. Each area has different capacity, and this can be a premise used to create the possible scenarios for pauses. For example, the area that has a larger capacity can stop for the pause, accumulate the product and then, after returning, can use this capacity to process the accumulated product. In the plant in study, the cut and packing areas have 15% more capacity compared to slaughter area. This capacity difference is used to project a scenario where it is not necessary to keep all areas running during pauses.
- Extension of pauses: in the areas in which was decided to have pauses, they will be of 20 min, not 15 min (two considered options). This premise is an agreement between the factory and security areas, because it allows a repairing rest to the employees and creates less set-up-pauses in the production line.
- Minimum number of workstations to be replaced per employee: the substitute employee must have ability to substitute at least three different posts.
- Necessity of labor to substitute pauses, determined also by gender: because of the needed physical force in certain activities, it must be considered the employee's gender.

The scenarios were established as shown in Table 8 in which it should be tested in the model to evaluate the best option, according to the current necessity of the plant.

There is a sequential execution logic that the program uses to create the scenarios and evaluate the results:

- The number of pauses, the shift schedule, pause schedules and the areas that will have the pause are set. These are entry variables to generate the scenario.
- The model starts the production, counting the entries and exits of product second by second per employee in each operative post.
- During the pause, it is calculated the potential amount of accumulated product in each operative post, assuming that the employee will stop the pause and the product will continue to pass.
- Based on this potential amount and on the unitary time, registered in the program data base (data provided in the first phase of the model construction), to do the activity of each operative post, it is calculated the necessary time to process the accumulated amount of product;

- The program resizes the amount of stations to substitute, between the pauses intervals. For each station substituted in the pause is done this modeling and, this way, it consolidates the total resize of necessary employees for substitution in the pause, according to each scenario.

4.2 Resulting scenarios – resizing pauses

The five scenarios planned in Table 8 were simulated in the plant model. Each one generates an exit of production variation and extra employees demand to cover the pauses. Table 9 shows the summary of the simulated scenarios results.

As described before, the best scenario to choose depends on the current and future production forecast of the plant. In Table 10 are shown the best scenario choice according to demand level. This table must be used to support the manager to take the correct decision.

If there is a scenario of demand of maximum capacity occupation of 85%, for example, the most favourable is scenario 0, and also the easiest one to be implemented, as it does not require extra hiring and multiple tasks training. If the demand is too high or demonstrates rising, the scenarios 1 to 4 must be evaluated. It must be emphasized scenario 4, which, in terms of production, is the same as scenario 2, but takes into consideration the premise of using the overcapacity in cut area. The big advantage is the reduced number of extra employees, because the overcapacity would be enough to absorb production build up in the two pauses. This scenario must be evaluated with better detailing; supposing momentary carcasses build up, it must be evaluated to verify the structural conditions without

Scenarios	Description
Scenario 0	No extra team for pauses. The whole production line is stopped for the 3 pauses
Scenario 1	Extra team for 1 pause of 20 min per shift in all the areas. In 2 pauses per shift, the whole line is stopped
Scenario 2	Extra team for 2 pauses of 20 min per shift in all the areas. In 1 pause per shift, the whole line is stopped
Scenario 3	Extra team for 3 pauses of 20 min in all the areas
Scenario 4	Extra team for 2 pauses only in the slaughter area. In the cut area, the whole line is stopped and the velocity is increased to 480 swines/hour after the pauses to consume accumulated stock

Table 8. Scenarios to be simulated

Scenarios	Description	Extra team	Volume reduction (%)
Scenario 0	No extra team for pauses. The whole production line is stopped for in the 3 pauses.	0	−13.86
Scenario 1	Extra team for 1 pause of 20 min per shift in all the areas. In 2 pauses per shift the whole line is stopped	69	−10.46
Scenario 2	Extra team for 2 pauses of 20 min per shift in all the areas. In 1 pause per shift the whole line is stopped	80	−8.33
Scenario 3	Extra team for 3 pauses of 20 min in all the areas	119	0
Scenario 4	Extra team for 2 pauses only in the slaughter. In the cut area, the whole line is stopped, and the velocity is increased to 480 swines/hour after the pauses to consume accumulated stock	28	−8.33

Table 9. Scenarios simulated with results

interfering in any security or sanitary rules as, for example, carcasses temperature raising above the allowed, which is strictly controlled by sanitary inspection.

The best scenario choice depends on plant idleness, which is related to the current production demand. Table 10 is used to make the scenario choice decision according to plant capacity occupation rate.

5. Conclusions

The main contribution of this research project was the detailed description of the steps required for the modeling and optimization of a large slaughter plant, indicating which significant variables need to be considered during model construction, with the approach of evaluating and quantifying the opportunities to increase productivity and efficiency, starting from the initial process modeling in its current state.

The achieved productivity result in the modeling of large swine plant tested, balancing the workstations, considering the differences between takt time and task cycle time, demonstrated great application for slaughtering plants. For future applications in other pig plants, it will be necessary to update the current model with the characteristic data of each production line (capacities, layout, time of each task, number of employees), but the concept of using modeling as the way to process optimization has been shown to be applicable for animal slaughter, which has major challenges such as high product variability (animal weight and its genetics) and also a high rate of manual labor.

The correct selection of the software to perform the modeling is also an important point to highlight for future work, since the choice method considered the characteristics of the slaughtering processes, such as the important role of the modeling program in contributing to an analysis of increasing accuracy considering a specific distribution for each operator task time, being one of the most important points for this type of process, which has a large number of employees, where each of these has its own pace of doing the task, and is it is very important for the reliability of the model to find specific mathematical functions for these different variability rather than using mean values.

These results confirm the effective application of process modeling focused on large slaughtering plants (in this case, more than 800 employees) related to the optimization of the employed manpower, with a larger number of modelled workstations, superior to works mentioned in literature review.

Large-scale plant simulation, supported by robust software such as the one used, gives the speed and reliability needed to reach a conclusion that evaluates the entire production process. It is important to mention the significant result in productivity increase, which was possible with the reduction of 8% of the total time worked to produce the same production

Scenario	Scenario 0	Scenario 1	Scenario 2 or 4	Scenario 3
Scenario description	No extra operators needed for breaks. Even if stopping the factory in the pauses, it is possible meeting demand	Extra operators for 1 pause per 20-minute shift in all areas. In 2 pauses per shift, all line is stopped	Extra operators for 2 pauses per 20-minute shift (Scenario 4, only in slaughter area). In 1 pause per shift, all line is stopped	Extra operators for 3 pauses per 20-minute shift
Capacity occupation rate %	Recommended for Capacity occupation rate below 85%	Recommended for Capacity occupation rate between 86% and 89%	Recommended for Capacity occupation rate between 90 % and 92%	Recommended for Capacity occupation rate above 92%

Table 10. Scenario choice according to occupancy rate

volume, while performing the operating stations optimization. Considering that in this type of business the labor cost represents 80% of the total process cost, the reduction in labor cost achieved in the project application study contributed to decrease the total cost by almost 6%, and as the product is a commodity (fresh meat), this reduction becomes a competitive differential.

And finally, all the work was based on the main principles of LM, such as optimization of manpower resources, according to takt time (Jasti and Sharma, 2014) demonstrating the wide scope of application and effectiveness of the philosophy. Due to the size and complexity of the process evaluated, modeling and simulation was decisive to achieve the overall view of plant optimization, generating the reliability required to make the decision to remove more posts that were identified as an opportunity for reduction of cost.

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Corresponding author
Carlos Coutinho Fernandes Junior can be contacted at: carloscoutinhojunior@yahoo.com