Application of Value Stream Mapping methodology to the Ford Production-Unit at Schnellecke Logistics

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Abstract
Manufacturing is among the most competitive business-sectors worldwide, and such competitiveness has been growing in the past few decades. The automotive industry, being the lead party within the manufacturing sector, is known for its pioneer advances in production and quality management. *Lean*-Manufacturing arises, precisely within the auto-industry, as the state of the art in efficiency management, aiming to reduce operational costs while assuring high quality levels. 6-Sigma, an alternate management system, aims at reducing variability of processes' outputs granting increased quality levels. When combined correctly, these two systems complement each other and bring great competitive advantages to companies who adopt them.
Schnellecke Logistics is a company that provides services to major stakeholders in the auto-industry. The work developed in this thesis, emerges within this context and aims at evaluating and improving the productive system of Schnellecke's Ford Unit, in Palmela, Portugal. The main scope of this project was to identify inefficiencies (wastes) in the production flow and target the most critical situations: inventories with highest Lead-Times and workstations with the lowest performances. To do just that, the Value Stream Mapping methodology proved to be essential. However, despite its high versatility, it lacked the means to map multi-products with overlapping courses of value creation. Hence, an alternative method with an improved methodology (quite useful to this case study) was developed during the mapping stage – Multiproduct Value Stream Mapping (MP-VSM). During the improvement stage, different Lean and 6-Sigma methodologies were used, namely: SMED, process variation reduction, lot-size reduction, Kaizen event to reduce cycle-time, and various layout changes to greatly cut movement and waiting times. The orchestrated results, lead to a noticeable reduction in WIP-inventories, and lower production times as well as a strong increase in time available for setups, which can be used to further decrease lot-sizes (and WIP).

Key Words: Lean Manufacturing; 6-Sigma; TPS; Multiproduct Value Stream Mapping; JIT; SMED; Design Of Experiments

1. Introduction

Competition in the manufacturing sector has been visibly growing in the past few decades. Production and quality management systems have, in turn, become more efficient and more mainstream.
Lean-Manufacturing arose as a revolution in the production management systems, during the 90s. It has proved time and again, that it can drastically reduce operating inefficiencies (regarded as wastes) of any production system. 6-Sigma, is another management system that has been gaining momentum lately. As a quality focused system, it concentrates on reducing the variance of the processes. The two combined, usually bring great results to companies that adopt them (Franchetti, 2015) (Stern, 2015).
The current work was developed at *Schnellecke Logistics* (S-PT), in Palmela, Portugal, as a case study. It intends to analyze the present situation of its Ford production-unit: identify its inefficiencies and target the most critical ones for improvement. To this end, various Lean and 6-Sigma methodologies were used, namely Value Stream Mapping (VSM), Single-Minute Exchange of Die (SMED), Design of Experiments (DOE), among others.

2. Historical Background

Taylor is considered by many, to be the first contributor to turn management into a science. He pioneered observing and documenting working procedures in order to increase efficiency (Taylor, 1911) (Maynard *et al*., 1948). Ford became the next reference on this subject, when in 1914 he implemented practices in his Model-T production facilities, that lead to great economic success. The practices that lead to mass-production: normalization of products, use of specialized equipment (dedicated to a single function) and favorable salaries (Holweg,2007).

In parallel, on the other side of the Pacific, Sakichi Toyoda invented and successively reinvented the loom, in Japan. His ultimate version had built-in mechanical sensors that detected errors and interrupted production autonomously. The concept that derived from this behavior is one of today's major pillars of *Lean*-Manufacturing – *Jidoka* or Autonomation. His son, Kiichiro, improved the layout of the loom factory, to generate sequential flow, also creating a new concept – *Just-In-Time* (JIT). These two concepts were, for many decades, the foundation of the Toyota Production System.

2.1. Toyota Production System

Kiichiro Toyoda establishes the Toyota Motor Co., with his father's help (Sakichi), in the mid-30s. His cousin Eiji Toyoda, takes the reins of the company in the 50s. With vital help from engineer Taiichi Ohno (former engineer at Sakichi's weaving factory), they developed the Toyota Production System.

Jeff Liker, a professor of industrial engineering, names 4 categories of principles that summarize this system (Liker, 2004) (Toyota-Global, 2010):

- *Long-term philosophy* - investments intended to improve competitiveness, will ensure sustainability and longevity to the company
- *The right process will produce the right results* - using reliable and thoroughly tested technology, while using "pull" system and leveling the workload (*Heijunka*)
- *Add value to the organization by developing your people* - investing in the people is identified (by Liker and the Toyota company itself) as a key factor
- *Continuously solving root problems drives organizational learning* - continuous improvement efforts (Kaizen) will constantly elevate the standards of the company and lead to better results and competitiveness.

3. Lean Manufacturing

The word *Lean* embodies the concept behind this management system: a *Lean* production system, is one with no "fat" - where fat is a metaphor for wastes or inefficiencies.

Hence, *Lean*-Manufacturing stands for a series of methodologies, principles and tools that aim at identifying and eliminating all wastes of the production system. Ohno identifies 3 categories of wastes (Ohno, 1988):

- *Muda*: Transport, Inventory, Movement, Waiting, Overproduction, Over-processing and Defects
- *Mura*: lack of production leveling (*Heijunka*). To correct this, *Lean* companies aim at creating a continuous flow and work in JIT
- *Muri*: unreasonable overburdening of people and machinery

Most literature (and companies) have a tendency to focus on trying to eliminate the 7 Muda wastes, as they tend to be easier to understand and to target. (Womack, 2006)

Kaizen and 5'S, sustaining continuous improvement

Kaizen, translated from Japanese, means "improve" and reflects the underlying philosophy of the continuous improvement, typical of *Lean* (Womack *et al.*, 1990) (Imai, 1986). The main goal is to increase the productive system's competitiveness, by constantly improving (processes, procedures, …) and setting new higher standards with each improvement. (Kaizen Institute, 2013)

The 5'S methodology increases labor organization and is essential to standardize work. By setting a designated place for everything, it becomes clearer to figure out what could/should be changed, which also favors the continuous improvement efforts (CSS, 2015).

Total Productive Maintenance (TPM) and Jidoka, assuring quality

The TPM system aims at maintaining and improving the integrity of the equipment and processes, leading to higher *Overall Equipment Effectiveness* (OEE). As a consequence, production systems tend to have fewer downtimes (Nakajima, 1988).

The concept of automation is widely known; however, an automatic equipment may not be autonomous, as it could produce a whole batch of defective products before being noticed. Jidoka aims precisely at preventing such occurrences, by equipping the machines with sensors and mechanisms that detect defects and promptly interrupt production (Womack *et al.*, 1990).

Takt-Time (Pull flow) and JIT

One of *Lean*'s identified wastes is *Inventory*. By adopting sequential production, with pull systems, *Work In Progress* (WIP) inventories tend to decrease. A productive system with faster Setup times tends to be more versatile, meaning it can produce lower lot-sizes and consequently can also reduce WIP inventories and Lead-Times (Womack *et al.*, 1990).

4. 6-Sigma

Processes with high variance account for quality failures. In order to minimize such variance, 6-Sigma features the DMAIC methodology and indicates sets of tools for each step of the way (Bagchi, 2011).

DMAIC methodology

To implement this methodology, typically one starts off by *Defining* the issue, from identifying the root-cause for the variance. Then proceeds to *Measure* the key parameters of the process and product, to *Analyze* them and establish cause-effect relations. Once identified the regression model that relates dependent variables with the independent variables, one *Improves* the system by implementing the corrective measures, and sets a *Control* plan to ensure it has indeed been corrected effectively (Franchetti, 2015) (Stern, 2015).

5. Lean and 6-Sigma tools

5.1. Value Stream Mapping (VSM)

This methodology presents a standardized mechanism of illustrating value creation in a productive system. Its simplicity allows all employees to participate in its analysis (Lasa *et al.*, 2008) making it a preferred tool of *Lean* to identify inefficiencies in a productive system (Rother and Shook, 2003).
It is also advised to include various departments of the company to elaborate the map, as well as the decision-makers for effective results (Lasa *et al.*, 2008).
An *Improved* version of this tool (IVSM) was introduced by Braglia (*et al.*), aiming to increase its versatility, and enable multi product family analysis (Braglia *et al*., 2006). This approach, claims one should identify the system's most prominent product family (and provides guidelines for the reader to do just that), then map it and focus on improving its path of value creation (Braglia *et al*., 2006).

5.2. Single-Minute Exchange of Die (SMED)

Shingo, a consultant industrial engineer for Toyota, is credited with the invention of the SMED methodology. It presents a systematic method to dramatically decrease the downtime originated from setups (Shingo,1985).

5.3. Kanban System

This communication system between client and supplier, developed by Ohno in Toyota, greatly helps reaching JIT. By allowing the client to signal the need to replenish the buffer, it ensures that the supplier will produce "only what is needed, when it is needed, and in the amount needed." (Toyota-Global, 2010) (Christopher, 2011).

6. Methodology and Diagnosis

The production-unit, analyzed in this work, produces 14 references (12 to Ford and 2 to Mercedes). These products are glass profiles and glass-divider bars (frames for the windows) for the *Ford Transit Connect* and the *Mercedes Vito* and *Viano* models.
The production process starts with a coil of steel that goes through a roll-forming station creating profiles. These profiles then undergo further mechanical processes (bending, blanking and welding of brackets) in3 other workstations until they are ready for delivery.

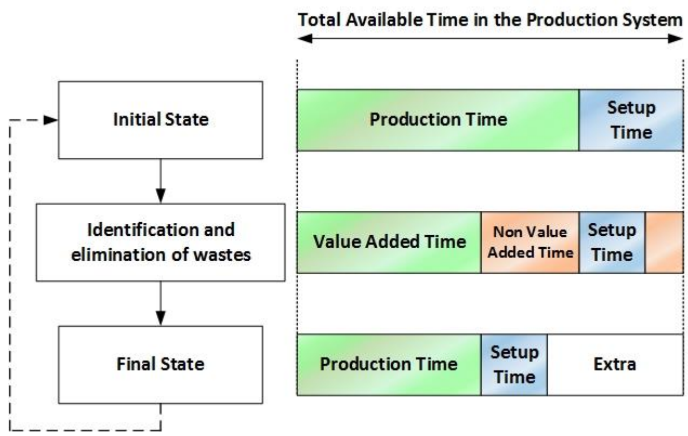

Figure 1 - Schematic representation of time distribution assessment

The company knew upfront, that the production system of its Ford Unit was working with excess capacity, as effective deliveries were consistently lower than the forecasts emitted by the client. Therefore, its objective was to assess the (current state) system capacity and increase its efficiency. Hence, in order to reduce the large inventories of WIP and finished parts, an assessment to time distribution was due (Figure 1).
The goal was to decrease Setup times, as well as Production Times, in order to have some extra time available for Setups – allowing for a decrease in EPEI, which means also decreasing lot-sizes and ultimately reducing WIP inventories.

6.1. VSM methodology

The objective now, was to find the most critical inefficiencies: workstations with lower performances (lower VAT%[1] and Occupancy Rate) and inventories with highest Lead-Times.

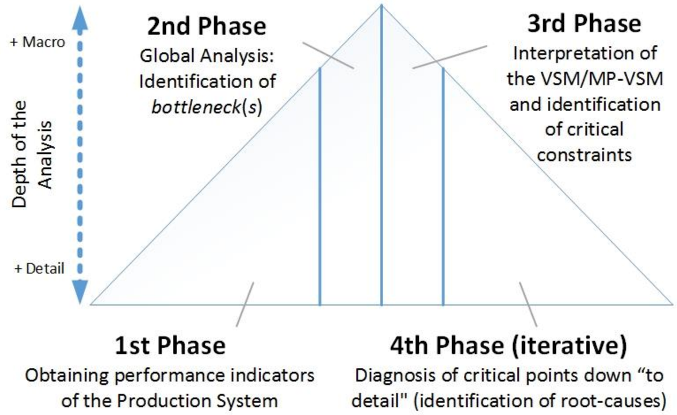

Figure 2 - Methodology used (based on VSM)

The adopted VSM methodology can be schematically represented by a pyramid (Figure 2). In a preliminary learning stage, one had to do the recognition of the production system, which facilitated the identification of KPI's that could be included in the VSM.

Obtaining Indicators

The first phase consisted of gathering and calculating indicators, corresponding to a growing level of "abstraction" in the analysis. Started with measurement of cycle-times and ended on a "macro" perspective by establishing Takt-Times and calculating Lead-Times.
In between, *activity-records*, and *production-records* (provided by the company) were analyzed to assess, for each workstation: occupancy rates, Value Added Times (and VAT%), Setup times and lot sizes.

Identifying bottlenecks

The measured cycle-times turned out to be far below the real cycle times. All workstations incurred in frequent stops, therefore as a first approach, these (real cycle-times) were determined from the number of parts produced in a shift, divided by the working time (of the same shift) discounting the time for Setups and any unexpected interruptions.

With the data gathered it was now possible to calculate the production time of each workstation, based on the weekly forecast[2] of future sales.
The Roll-Forming and the Divider/Static stations were identified as the two stations with highest production time requirements and regarded as the critical workstations of the production flow.

Building and Interpreting VSM (and MP-VSM)

During the mapping process, a significant difficulty arose: all product families passed through the Roll-Forming station (which was already the bottleneck). At first, two solutions came up:

- Identify the predominant product family in the system and focus on improving its path of value creation (Braglia *et al*., 2006)
- Elaborate multiple VSM's, one for each product family, and try to establish relations.

NOTE: in the Roll-Forming station, each tool has a different Setup time, with different lot-size and different frequency of production (planning was random, meaning EPEI tends to infinity).

In an attempt to map all products in a single VSM, a third alternative arose, the creation of a *Multiproduct Value Stream Mapping* (MP-VSM), presented in attachment of the thesis.
A VSM of the predominant product family is presented (Figure 3). The MP-VSM condenses all the information of the productive system, which made it possible to identify the following situations:

- The occupancy rates and VAT% of all workstations are fairly low
- All buffers have long Lead-Times
- The Roll-Forming has the longest Setup times

6.2. Diagnosis and Root-Cause Analysis

Low Occupancy Rates

The low occupancy rates were consequence of an oversizing of the capacity of the production system, during its project. The Unit had been designed to produce parts for 1100 cars, with a maximum capacity of 1400 cars, daily – during 2015, the average demand was around 550 (cars/day).

Generalized Non Value Added Time (NVAT%)

To assess the low VAT% of all workstations, the course was set to find out the distribution of the NVAT%.

[1] Value added time as percentage of production time

[2] 1σ was added to the mean value of each product's throughput, to increase the resilience of the production system.

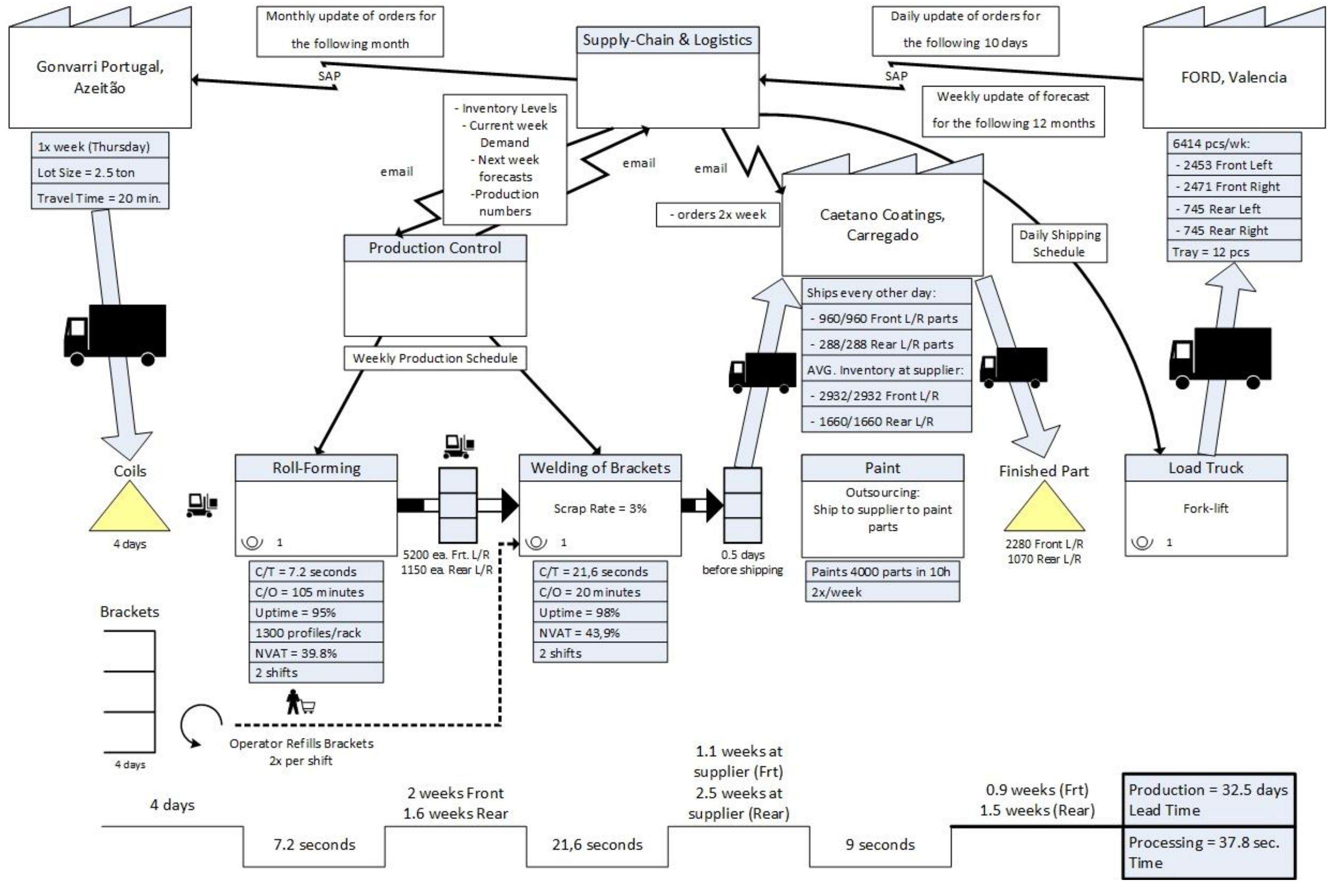

Figure 3 - VSM of Frontal and Rear Dividers (Left and Right)

Two conclusions were drawn:

- The predominant motive for stops (in all workstations), fell in the category "Quality Control". Turned out, it was the operators themselves who were responsible for *measuring parts* and proceeding with *machine parameter adjustments*.
- The Divider/Static station had an unusually high portion of time falling in the category "Other stops" which were unaccounted for.

This analysis had been made with the objective to find if there were any issues that were common to all workstations, and it did just that. Turns out the operators had to frequently monitor the output of their work because it had too much variance. After some root-cause analysis, the conclusion lead to the raw-materials' mechanical properties having themselves, too high variance.

The Divider/Static operator usually started working around 25 minutes later than his colleagues, for he had to wait for them to use the Unit's computer (to register the measurements of the first piece produced). He also had to refill with brackets at the supermarket, which was placed outside the Unit.

Pareto Analysis

An individual analysis of each station's procedures made it possible to identify the actions with highest contribution to NVAT%.

A new finding emerged: the coil exchange and the swapping of racks, in the Roll-Forming and the Divider/Static respectively, were the procedures causing the highest total stop time.

The coil exchange procedure was subject to SMED methodology.

It was easily diagnosed that the layout was unfavorable for the Divider/Static station. Adding to the fact that the operator had to refill outside the unit (supermarket) and wait for the rest of the crew to start working, he was also performing the rack exchanges using manual pallet trucks, whereas the other workstations called the forklift do the swap (from the Logistics production unit).

This Pareto analysis also identified that among all of the Setups performed in the Roll-Forming station, the Setup for the Divider tool was causing the highest impact, making it the choice for another implementation of the SMED methodology (this conclusion was also drawn from the MP-VSM).

Table 1 - Summary of improvement suggestions

Workstation	Situation	Method
All	Quality Control Stops	Variance Analysis (DOE, SPC)
Roll-Forming	Setup time	SMED
Roll-Forming	Coil Exchange	SMED
Divider/Static	Rack Exchange	Layout changes
Divider/Static	Waiting at start of shift	New support station
Divider/Static	Electrode Milling[3]	Extra set of electrodes
Frontal Glass	Cycle-Time	Kaizen to reduce cycle-time
Frontal Glass	Rack Exchange	Buffer creation[4]
All	WIP Inventory	Lot-size reduction

Lot-Sizes and Setup cycle

From analyzing the Lead-Times, it was possible to identify that the products with lower throughputs (imposed by the client) had the highest Lead-Times. For these cases, it was assessed that the size of the rack established the lot-size (of up to 5 weeks' worth of Lead-Time).
On this final stage of the diagnosis, it was also found that the unit had capacity to perform Setup cycles weekly, alongside the weekly production (in current state conditions) (analysis based on Figure 1).

6.3. Summary of the encountered constraints

Table 1 presents a list of the critical constraints (as well as some other identified situations with room for improvement) and the approach to be used in eliminating or mitigating the issues at hand.

7. Solutions

7.1. Quality Control interruptions

To reduce the occurrence of these interruptions, firstly, one set out to confirm the diagnosis of the root-cause (raw materials). It was therefore suggested, to increase the grade of the raw materials and then observe if the *adjustments of machine parameters* became less frequent. Assuming they have (the company has yet to implement this change), it is then possible to perform a DOE to assess the best settings and significantly decrease these adjustments (both in frequency and time).

As soon as it is verified that the processes' variances have been reduced, the team leader may give instructions for the operators to reduce the frequency of the measurements – significantly reducing this category of interruptions.
Some guidelines for SPC implementation are also presented in the thesis, aiming at further decreasing the need for *product measurements* interruptions.

7.2. Setup-time reduction Roll-Forming station

The implementation of the SMED methodology was indispensable to greatly reduce the Setup time in this workstation.
Several procedures, pertaining to preparation of the Setup, were identified as external operations – meaning they could be executed before or after the changeover. One internal operation was converted to external – an extra stamp-matrix that was regarded as spare part, started being used, and the stamp exchange could be executed before the Setup.
Finally, a rearrangement of the procedures and some additions, alongside an extra hand (2 operators to perform the Setup instead of 1) managed to further reduce the overall Setup time.
Altogether, this study allows for a reduction of 52% or about 1 hour in the Setup.

7.3. Coil Exchange in Roll-Forming station

To reduce this procedure, the SMED methodology proved useful again. Some external activity was identified and some small alterations allowed a

[3] The operator had to wait for the maintenance technician to do the milling of the electrodes.

[4] Currently the exchange is performed by the Logistics department, using forklift. The operator could do the swap alone, faster, if there was a buffer-rack on wheels.

reduction of 49% to this procedure, or roughly 4 and half minutes. This may seem a small gain, but this procedure occurs quite frequently (3 to 5 times per shift) and had been identified as the practice that lead to highest interruption time in this workstation.

7.4. Increase of the overall performance of the Divider/Static station

Some alterations to the layout of this area could strongly benefit this workstation. They would reduce the rack exchange times, the supermarket refill trips and even Setups could benefit from a time reduction. Adding a new support station, with a computer to register the measurements (at the beginning of a shift) a SAP "reader" for faster production registration and a printer (to print the rack labels) would also increase the performance of the station.
Finally, adding a spare set of resistance-welding electrodes for each die, would eliminate the waiting time of the milling procedure – occurs once a week and lasts 25 minutes during which both the operator and the workstation are stopped. Altogether these changes should reduce this workstation's production time by 7,5% or about 4h 45min weekly.

7.5. Frontal-Glass stations

Some room for improvement was encountered in these workstations (there is a Left and a Right version of the station) despite not being *bottlenecks* of the production unit.
These stations were (each) composed by two machines, and the first had a cycle time far superior than the second. The two machines would start their respective cycles together, after the operator finished placing the products on both. Changes were made to allow the first machine to start the cycle sooner, representing a gain of 10% on the cycle time (4 seconds).
A buffer "on wheels" was also added to each station, allowing the operators to perform the exchange of racks themselves, faster than previously (they used to wait for the forklift to perform this exchange).

7.6. WIP inventories reduction (from lot-size reduction)

Calculations were made to assess how much productive time and how much time available for Setups, each station would have after the proposed alterations.
In addition, three scenarios are presented, comparing time distributions (according to Figure 1) of the whole unit (Table 2).

1. The first scenario states current conditions,
2. The second scenario simulates reducing lot-sizes to current weekly demands, while keeping current conditions (no alterations from the Solutions presented)
3. The third scenario simulates putting in place all suggested alterations and lot-size reduction (same as the previous scenario)

The last scenario, when compared with the first, shows a reduction of 15% of overall production time, sided with an equal time dedicated for Setups (although the number of Setups increased substantially). This third scenario also represents Lead-Times of 1 week for all inventories (down from an average of 3,2 weeks), because all workstations would be producing the mean value of the weekly forecast.

8. Conclusions

VSM and alterations

As expected, the underlying methodology of the VSM tool, proved to be very helpful. However, despite its high versatility, some tweaks were made in order to map multiple products. The MP-VSM that arose from these alterations turned out to be quite helpful for this case study.
When trying to implement the solutions (for the encountered constraints) it turned out to be quite difficult to convince the company (and even the operators) to adopt some of the changes.

Table 2 - Comparison of Time-Distributions between the 3 considered scenarios

	Scenario 1 Current conditions	Scenario 2 Current conditions "in JIT"	Scenario 3 Final
Productive Time	234h 35min	234h 35min	198h 42min
Setup Time	14h 09min	20h 48min	14h 03min
Extra Time	11h 08min	4h 29min	47h 07min

This behavior is broadly mentioned in literature, and perhaps the lack of inclusion of the management executives in this process, could have been the root-cause for this difficulty – situation also described by Jasti and Sharma and as Lasa, Laburu and Vila had advised: one should include every department and management in the VSM process (Jasti and Sharma, 2014) (Lasa *et al.*, 2008).

Lean

The company already had a Lean department, meaning the concept was not new. This department is doing a great job raising awareness for waste reduction (hosting training events for the employees) and continuous improvement implementation (through Kaizen events). However, the goals established by the Schnellecke group headquarters seemed a little too high for the current reality of the company, which is surrounded by an environment of high competitiveness and finding it hard to invest.

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