Application of Lean Methodologies in the Maintenance of Aircraft Engines

A Case Study at OGMA

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Abstract

In the context of an increasingly competitive global market with sudden and unexpected transformations, some enterprises see their volume of business and market share decrease as new players emerge. Resulting in an increased scarcity of finantial resources, the companies are compelled to increase their operational efficiency, in order to mitigate the costs and maitain and increase their profit margins. It is in this segment that the Lean methodology appears with the objective of eliminating wastes, increasing standardization, increasing the company's services flexibility according to the client demand and implement a culture of continuous improvement.

The present paper intends to employ Lean methodologies and Lean tools to diagnose and propose solutions regarding the improvement of operational efficiency of the portuguese aeronautic enterprise OGMA in the extent of Maintenance, Repair and Overhaul of aircraft engines.

Regarding the company, the volume of business of OGMA regarding the engines maintenance is jeopardized by the shorter Turn Around Time delivered by its direct competitors. For this reason, it is intended to reduce the current total time of maintenance, hence achieving the highest possible client satisfaction through quality and on time delivery compliance and thus increasing competitiveness in the global market.

Keywords: Lean Methodology, Maintenance Repair Overhaul, Operational Efficiency, Aircraft Engines

1. Introduction

The aeronautic Maintenance, Repair and Overhaul (MRO) industry is often characterized by an environment of low product cadency and high diversity of required maintenance processes. This may suggest a certain incompatibility with the Lean ideology which defends processual standardization and achieved opperational efficiency backed by a extremely high product cadency. However, as inspected by Lane [1], Lean ideology can be exploited to be correctly implemented in these environments and excel at improving the operational efficiency of a high diversity and low volume plant. Any company inserted in this context has to be able to accomodate high client fluctuations, and be flexible enough to achieve high efficiency both in moments of high and low work load. In this segment, the plants have to be planned to accomodate over capacity, with a high multidisciplinarity of its workers.

OGMA is set to endure full overhaul of aircrafts being divided in three different segments, including maintenance of aerodynamic structures constituted mainly by the phuselage and wings, fabrication of aeronautic structures components and engines maintenance. The present paper is inserted in OGMA's engine MRO segment and is fueled by the necessity of the enterprise to increase its volume of engines capacity preconditioned by the market forecast demand. With a recent reduction of business volume in the past years, the current enterprise situation results in a scarcity of finantial resources. For this reason, OGMA's vision is to increase the volume of engines overhauled annually to increase its revenues, however the increase in the capacity has to be endured without major investments due to the lack of the enterprise liquidity.

In the context of achieving high gains with low investment, it is employed Lean methodologies and tools to reduce wastes which do not aggregate value to the MRO processes and increase the operational efficiency of the plant. The increased efficiency is achieved with the reduction of the time each maintenance process takes in the plant by tackling the waiting times and distances traveled by both the technicians and the engine parts inside the shop to achieve a reduction on the Turn Around Time (TAT). To analyse and diagnose the processes with inherent potential improvement, it is employed the Lean tools of Visual Management, Value Stream Mapping (VSM), Yamazumi chart, Ishikawa diagram and Spaghetti diagram.

The aims of the present work arise from the framework described previously and are set to develop and define standard procedures and solutions, which ensure that the company is able to accomodate the increase in volume of engines due to the market precondition. The following items describe the aims:

- Diagnose the current line of maintenance in order to analyze the activities with potential improvement;
- Propose a viable approach to the improvement of the MRO line in terms of opperational efficiency, utilizing Lean methodologies;
- Reduce the TAT of the engine maitenance in order to accomodate an increased volume of engines.

With these aims accomplished, it is expected that the company reaches a state where both the increased client demand and its fluctuations are smoothly accommodated with a parallel increase in efficiency both in high and low work load periods.

2. Literature Review

Lean manufacturing is an approach of ongoing improvement within the management of an organization which contributes with tools for the efficienty execution of a project. Its primary objective is to add client value by reducing the waste in terms of time, human effort and expenses.

It derives from the Toyota Production System (TPS), which is an organizational and technical system developped by the car manufacturer company Toyota with the main objectives to reduce three types of wastes: Muda, being the activities that do not add value to the client; Mura, which is the unevenness in the activities of a project or the lack of standardization; Muri, addressing the overburdening of the machinery and operators [2].

2.1. Lean Concepts

Lean manufacturing can be defined by the concept of Kaizen, which translates from the japanese into change for the better. As the expression indicates, it refers to an ongoing process of transformation to achieve ultimate efficiency and minimal waste. Moreover, Lean manufacturing can be achieved through the implementation of several groundwork concepts such as process standardization, and Heijunka which can be translated into leveling and consists in a production system controlled by the client demand [3].

Regarding the pillars of a typical lean organization it appears the concept of Kanban, which can be translated from the japanese into visible card. This term refers to an operational system where a material is produced or moves along a line of production only when it is required ususally by means of a visible card containing the material information. Together with the Heijunka mindset, Kanban enables a production system where the produts are made just in time (JIT), avoiding excessive inventory [4].

The Lean methodology can be characterized by five principles according to [5]:

1. Value: Identifying what the stakeholders perceive as the value of the project.
2. Value Chain: All the necessary activities in a line of production/maintenance
3. Create flow: Ensuring the product moves in the line of production/maintenance through every value action with the correct cadency, avoiding bottlenecks.
4. Establish Pull: Reffering to a production system where the finished goods are ready to be delivered when the costumer requires them.
5. Seek perfection: A mindset of no bounderies regarding the processes of ongoing improvement.

2.2. Lean Tools

Some of the Lean tools employed in the present work are the following:

- Visual Management: The arrangement of information in an explicit and easy to consult manner, hence enabling the effective identification of anomalies.
- Visual Stream Mapping: A process mapping of the value added activities containing the flow of material and information between stations. Contains both the value-added times and the non-value-added times enabling the sistematic identification of wastes and determination of what can be improved [6]. Together with the displayed total times of added and non-added-value activities, it is computed the Takt Time, which is the time period at which two consecutive products should leave the line of maintenance, according to the client demand.

$$\text{Takt Time} = \frac{\text{Production time/Day}}{\text{Products ordered/Day}} \qquad (1)$$

- Swim Lane diagram: An extension of VSM used to easily acknowledge the counter-flows and process repetition in a line of production.
- Yamazumi Chart: Provides information in a stacked manner regarding the temporal con-

tribution of value-added actions, necessary non-value-added actions and unnecessary non-value-added actions.

- Spaghetti Diagram: A diagram which maps the motion flow of materials and/or operators and interlinkage between process activities.

3. Case Study Framework

OGMA is a Rolls Royce authorized maintenance center and currently comprises the maintenance of the military T56 and AE family of 2100 and 3007 engines. With the necessity to expand its business, the company has won a contract resulting in the accomodation of a new AE family model, the AE1107, which will increase the volume of engines maintained annually, hence the line of maintenance has to be restructured.

The general procedure that constitutes the engine MRO of the company is visible in figure 1.

The workforce responsible for the engine reception captures the engine general physical condition. As the engine enters the line of maintenance, it is disassembled and each part is cleaned in order to be submitted to several performance testings which will conclude if a specific part is serviceable or needs repair. The preliminar set of tests is the Non-Destructive Testing (NDT), which is characterized by a series of inspectinons which do not affect the current state of the parts. The metrology is a dimensional evaluation, crucial for the great majority of the engines components, however specially important for the non-static parts like the compressor and the turbine. As the parts reach the evaluation stage, they are inspected by a specialized workforce which segment the parts in either serviceable or not serviceble, in which case it either can be repaired or has to be replaced. In the FOC phase (*Fim de Orçamento de Custo* which is portuguese for Cost Estime, CE) it is established a line of communication with the client in which it is presented the detailed information of the required MRO operation with its inherent price, according to engine condition agreed by the evaluators. The repair stage is characterized by several stations of lathe, milling machines and rectifiers and is constituted by a high diversity of inherent procedures for each of the around 1000 different parts in an engine and their repair requisites.

As all the parts become serviceable, the engine can be assembled in two stages: first each module is assembled (with the comprised modules being the Power Gear Box of a turbprop, Torquemeter, Exhaust components, Accessory box, Turbine, Combustion Chamber, Compressor and Diffuser) and second the modules are coupled in the final assemblage. Followed by a functional testing the engine can be expidited to the client after the confirmed payment. In a holistic approach, the entire MRO can be divided in two main stages: the preliminary phase, from the reception untill the evaluation and the repair phase, from after the evaluation untill the expedition.

Since examining over 1000 parts and their routes in the plant would result in an over extensive and unnecessary work, first it is acknowledge the universe of parts of the AE2100 (since it constitutes the main volume of business) which need to be reviewed in order to correctly plan the entire MRO line with the increased volume. In this segment, it is chosen 4 sample parts according to the following criteria: (i) the amount of resources employed in terms of time, labour and machinery in that part; (ii) the worst case scenario repair route; (iii) considerable frequency at which those parts need repair and endure that repair route. The agreement between the 3 criteria factors results in the following components: Main Drive Gear (MDG) which is a gear inside the module of Power Gear Box; Rear Turbine Bearing Support (RTBS), being the support for the rear end of the engine shaft; the Compressor Rotor, which is the main component of the rotating part of the compressor; Compressor Air Inlet Housing (CAIH), the air inlet carter supporting the front end of the engine shaft.

As a final note, these four parts have typical paths inside the repair phase and can be used as samples which characterize the entire operation of all the components. These 4 routes are characterized with stations interlinkage transversal to all parts, hence the entire line is examined. For that reason it is expected that the operational efficiency is enhanced across the entire processes of all the parts.

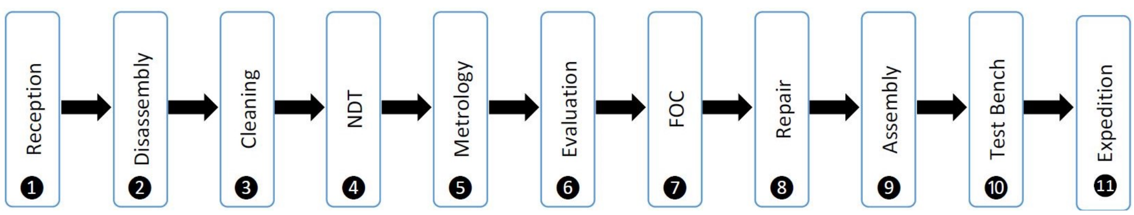


Figure 1: Generic MRO procedure in OGMA

4. Diagnostic and Analysis of Results

The planning of the line of maintenance according to the workload expected starts with the inspection of the engine forecast for the following 10 years (2019-2028). With the acquisition of the AE1107 model, the forecast results in a gradual annual increase on the volume of engines from 106 (2018) to a maximum of 174 (achieved in 2026), corrresponding to an increase of 64%.

With this data it is possible to compute the Takt Time which will serve as a refference to the maximum time each part should stay in a maintenance station. Using expression 1, the Takt Time shows that every 49.7 hours an engine should be expedited according to the client demand.

4.1. Current VSM

With the Takt Time as a refference, it is planned the VSM of the entire current MRO process of figure 2 with CT being the cycle time, LT the Lead time and WF the Workforce. The Kitting activity regards a space where the serviceable parts are redirected and accumulated before the assembly begins. For that reason it has the same cycle time as the repair. The bottom timeline provides the temporal aspect of the entire MRO. The values on top concern the Work In Progress (WIP) or iddling times before each station, the bottom values regard the CT of the activities. Concerning the 240 hours WIP before reception and the 336 hours of FOC, these times are mostly ruled by the client, hence are external factor which can not be improved. For this reason the FOC is not tackled with the present work. After the preliminary phase, the engine as a whole can no longer be considered, since the parts diverge in the most varied directions in the shop during repair. For this reason, this activity is analyzed deeper in detail in section 4.3 with another VSM diagram in the form of a swim lane. During the repair step, there are several processes of cleaning, NDT and metrology which are not inherent to the preliminary phase. The hours of these processes are not included as CT for the inherent centers of this VSM, being accounted inside the CT of the repair stage. Nonetheless, their CT also constitutes to the WIP of each of the stations of cleaning, NDT and metrology during the preliminary stage.

4.2. Inspected Issues

With the process flow established, it is endured an extensive analysis of each station to acknowledge what can be improved, resulting in the following aspects:

- **Reception:** The internal waiting time is average 12 hours.
- **Disassembly:** The current line is not sufficient to accomodate the increased volume; There is no specific workforce focused on this station.
- **Cleaning:** Lack of station capacity to process the parts during the preliminary circuit due to the flooding of the parts during repair, while there is a cleaning cabine obsolete.
- **NDT:** The parts during repair flood the station, while there is an NDT cabine obsolete.
- **Metrology:** The parts during repair flood the station, while there is a measuring robotic arm unused.
- **Evaluation:** Each evaluator operates in one engine, resulting in high CT ttimes.
- **Modular Assembly:** Missing hardware during assembly and lack of station capacity with

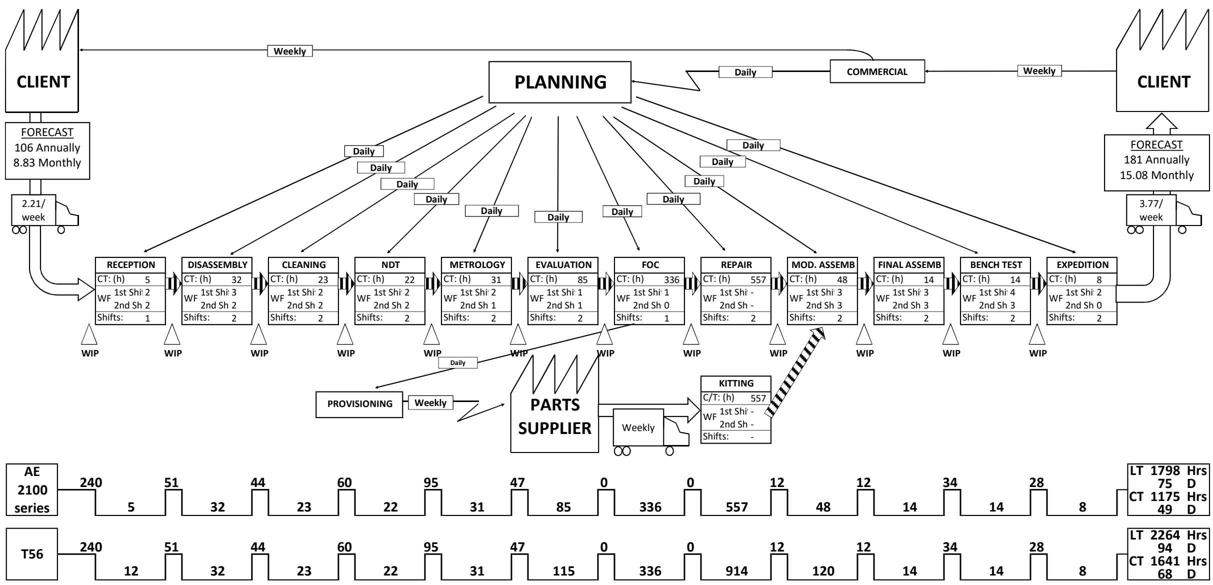


Figure 2: VSM before changes

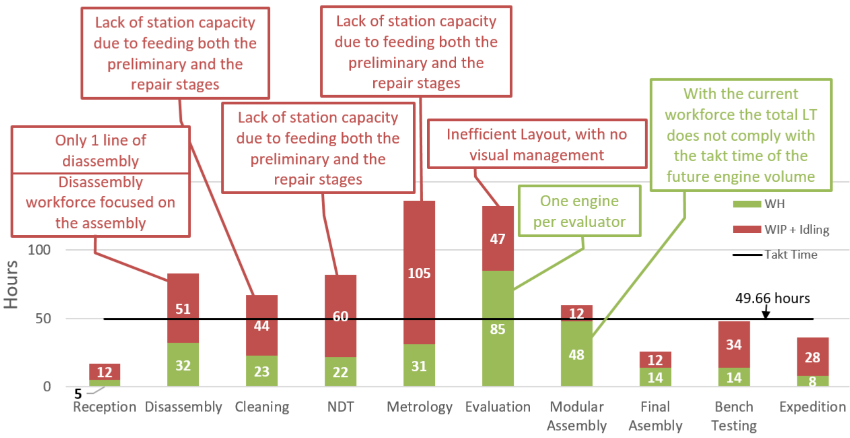


Figure 3: Yamazumi diagram with LT per station

the increase in volume.

- **Final assembly:** Within the Takt Time limit.
- **Bench Testing:** Within the Takt Time limit.
- **Expedition:** Within the Takt Time limit.

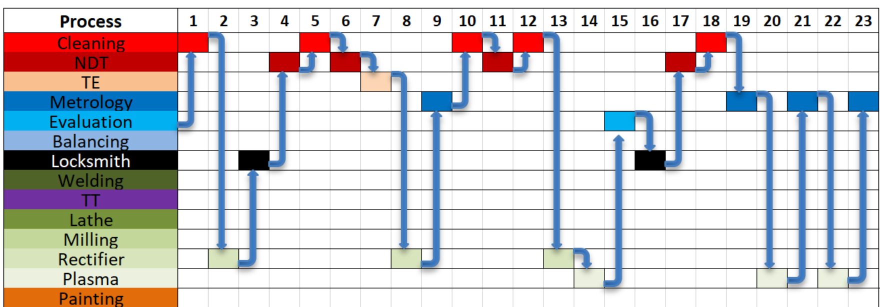
Figure 3 displays the LT for each activitiy with the Takt Time line and the resume of the inspected issues. It is segmented each activity in work hours (WH) in green and in idling times in red. The objective is to reduce the quantities in red, which is where the majority of wastes are located. The major bottleneck is located in the preliminary phase, particularly in the station of metrology. Nonetheless, the expected lead time of the evaluation is sufficient to become a bottleneck. Still in this segment, the aim of the present work is to accomodate the increase volume of engines, hence tackling the bottleneck and the potential one is not sufficient. For this reason, the entire set of activities which fall above the Takt Time line have to be time mitigated. Observing the green bars, they all fall below the Takt line, besides the evaluation. For this reason, the evaluation system has to be rethinked, since eliminating wastes is not sufficient by itself.

4.3. Current Process Flow During Repair

For the propose of the present paper, it is displayed the analysis of the most critical part, the MDG, since the issues inspected in this part are tranversal to not only the other 3 critical parts, but also for the entire set of over 1000 components. The swim lane diagram is displayed in figure 4. As a side note, the stations which are introduced in the swim lane diagram are: TE for Electrolytic Treatment, Balancing for the adjustment of rotating parts, Locksmithing, Welding, TT as for Thermal Treatments, Plasma surface coatings and Painting.

The main contrains regarding the repair concern the processes order which can not be swapped due to mandatory precedent activities and the fact that the WH are already carefully adjusted according to the inherent work, hence can not be reduced. For this reason the margin for reduction the repair LT lies in the mitigation of the WIP times.

The WIP before cleaning, NDT and metrology assumes high values since the stations are also requisited during the preliminary phase. Furthermore, the 4 major counterflows aref found when the parts head to the cleaning or NDT station (in 0→1, 2→5,



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total
WH	0.8	2.5	0.5	2	0.3	0.5	48	4	0.5	0.8	1	0.3	4	4	0.5	0.5	1.5	0.7	1	4	1	8	2.7	89.1 hours
WIP + Idling	12	12	12	48	12	48	24	12	24	12	48	12	12	8	12	12	48	12	24	8	24	8	24	468 hours
Distance	45	132	49	142	26	26	31	113	62	69	26	26	132	48	83	81	142	26	69	60	60	60	60	1568 meters

Figure 4: Current Swim Lane diagram for the MDG

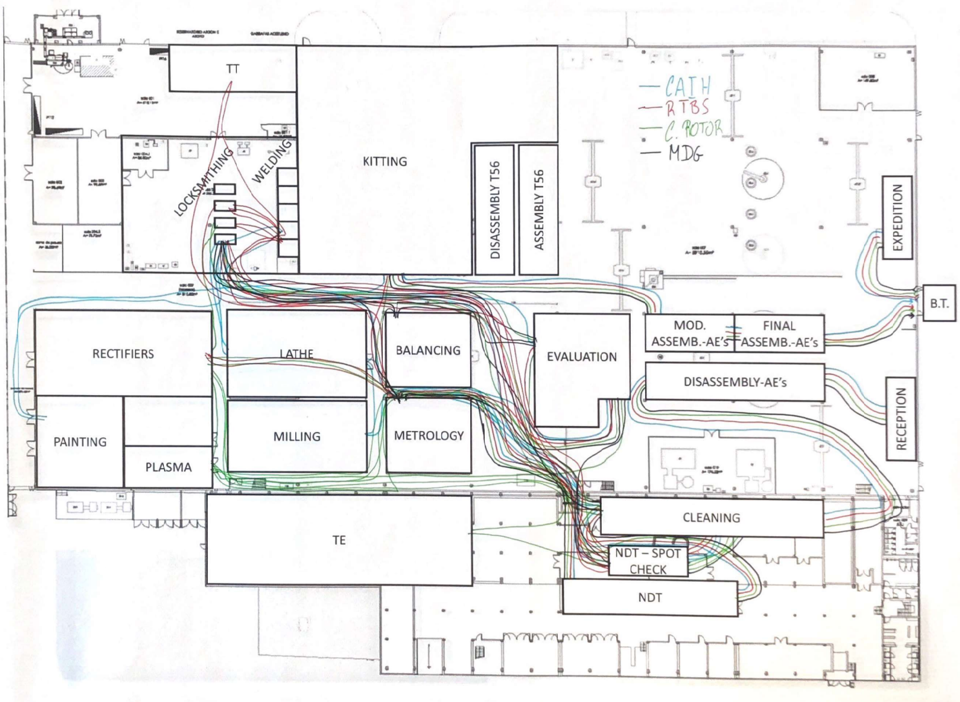


Figure 5: Current Spaghetti diagram of the plant

8→10 and 14→18). This type of counter-flow is particularly alarming since these stations are associated with considerable WIP and long distances traveled by the parts. This is due to the fact that these centers are far from the repair area since they are not located in the shop floor. Moreover, and not only in the case of the MDG, whenever a part moves to the metrology, it endures a considerable counter-flow (e.g. 20→21 and 22→23), also associated with considerable distances and idling.

4.4. Current Spaghetti Diagram

Alongside the diagnostic regarding the reduction of the waiting waste, it is also endured a Spaghetti analysis to acknowledge how the waste of avoidable motion can be mitigated, through layout alterations. In figure 5 it is observable that the highest density of flow lines regarding the four engine parts is located in two areas: (i) around the metrology and (ii) connecting the locksmithing/welding to the cleaning/NDT stations. Particularly for the metrology, the high density flux to the left of the station regards mostly the paths during the repair phase, while to the right concerns the feeding of the preliminary phase. Furthermore, the high flux connected to the cleaning and NDT station is coherent with the counter-flows analyzed in the previous section 4.3, and is also inspected for the other 3 parts as seen in figure 5. The repair machinery (lathes, milling machines and rectifiers) and the locksmithing/welding are alienated by closed walls and constrained accesses, inducing complex and lengthened paths, hence empowering lack of continuous process flow and high waiting times.

The rearrangement of the evaluation center can be analyzed with the zoomed in spaghetti diagram of figure 6. There are two types of wastes inspected

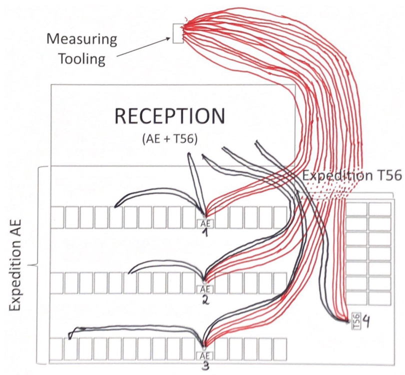


Figure 6: Current Evaluation Spaghetti diagram

in the evaluation: (i) waiting, due to the lack of organization of the reception area, resulting in the operator spending a considerable amount of time to find parts of its inherent engine; (ii) avoidable motion, since the measuring devices needed to perform the evaluation are shared with the disassembly line, hence are not at reach. It should be taken into consideration that the diagram does not display all the movements during the evaluation stage, because showing all the trajectories would result in a highly entropic diagram. For this reason it is only drawn a step of evaluating one part by each of the four evaluators.

5. Proposed Solutions

With the diagnostic endured, the proposed solutions are the following:

1. Creation of separate centers of NDT, Cleaning and Metrology to feed the repair stage. These processes during repair are simpler compared with the preliminary phase, hence can be endured utilizing the obsolete machinery;
2. Reorganization of the repair area;
3. Inclusion of multiple lines of assembly and disassembly;
4. Reorganization of the evaluation area.

5.1. Future VSM

With the improvements proposed, the VSM is unchanged in terms of process interlinkage. The improvements are noticeable in the reduction of the idling times, and for that reason the TAT is reduced from 75 to 51 days. Figure 7 displays the impact of the proposed solutions in the reduction of the WIP. The reduction in the disassembly and assembly lines is accounted for the additional lines. Regarding the highly requisited centers of cleaning, NDT and metrology, their WIP is reduced since the repair parts are now redirected to the second centers. To quantify these WIP mitigations, it is inspected that the number of engines simultaneously in the repair phase of the future plant setup is 5. It is then inspected the average time the total set of parts during repair of an engine is spent on the cleaning, NDT and metrology as WH. This temporal parameter multiplied by the number of engines in the repair can be discounted in the preliminary phase WIP.

Regarding the evaluation, it is proposed to implement a system where all evaluators work on the same engine, in order to distribute the CT through all the evaluators. Furthermore, the layout reorganization explained further in the present paper also contributes with a reduction on the WIP.

As a final note, it is now visible that the new bottleneck is located in the NDT area, with the total LT lieing above the Takt line. Nevertheless, it is endured a process analysis parallel to the present project which intends to tackle situations of documental setbacks, hence it is expected that at a final stage the stations LT all lie below the Takt line.

5.2. Future Process Flow During Repair

Figure 8 shows the impact of the second centers in the repair phase. Furthermore, in the following section 5.3 it is visible that the new centers of cleaning, NDT and metrology are located near the repair area, and for that reason the counter-flows are eliminated, resulitng in drastically reduced WIP and distances traveled by the parts.

As the centers are closer to the repair machinery, the counter-flows in the diagram shift down, meaning that the process is increasingly smoother with continuous process interlinkage. The reduction of the total LT segmented by WH and WIP is represented in figure 9.

5.3. Future Spaghetti Diagram

Figure 10 displays the future spaghetti diagram, representing the layout with the proposed solutions and the flow of the 4 critical parts in the shop.

The additional lines of disassembly and assembly are represented. By bringing the modular assembly closer to the kitting, the wastes of unnecessary motion endured by the technicians are mitigated in the event of missing hardware during assembly.

The high flow density around the centers of cleaning and NDT is now reduced, since these centers are set to feed the preliminary phase alone.

Since it is not possible to change the sequence of the activities, the reduction in the distance traveled is endured by clustering the high flow density inside the smallest possible area. In this segment, the repair zone is constituted by an open-area center where the entire repair machinery is aggregated together with the locksmithing and welding with the second centers of cleaning, NDT and metrology

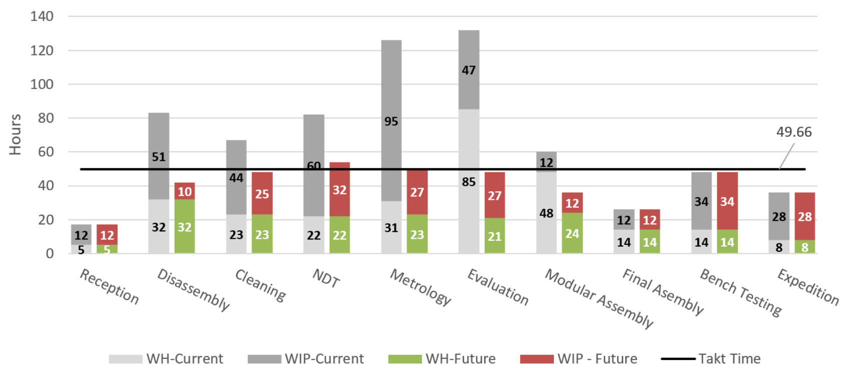
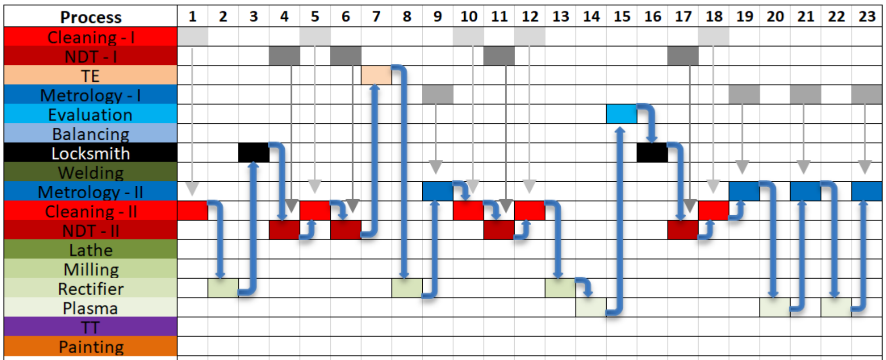


Figure 7: Yamazumi diagram regarding the impact of the solutions



Process	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total
Current WH	0.8	2.5	0.5	2	0.3	0.5	48	4	0.5	0.8	1	0.3	4	4	0.5	0.5	1.5	0.7	1	4	1	8	2.7	88.9 h
Future WH	0.8	2.5	0.5	2	0.3	0.5	48	4	0.5	0.8	1	0.3	4	4	0.5	0.5	1.5	0.7	1	4	1	8	2.7	88.9 h
Current WIP + Idling	12	12	12	48	12	48	24	12	24	12	48	12	12	8	12	12	48	12	24	8	24	8	24	468 h
Future WIP + Idling	1	12	3	2.5	1	2.5	24	12	2	1	2.5	1	12	8	12	3	2.5	1	2	8	2	8	2	125 h
Current Distance	45	132	49	142	26	26	31	113	62	69	26	26	132	48	83	81	142	26	69	60	60	60	60	1568 m
Future Distance	36	8	8	10	2	2	56	62	19	16	2	2	8	47	99	22	10	2	16	44	44	44	44	603 m

Figure 8: Future Swim Lane diagram for the MDG

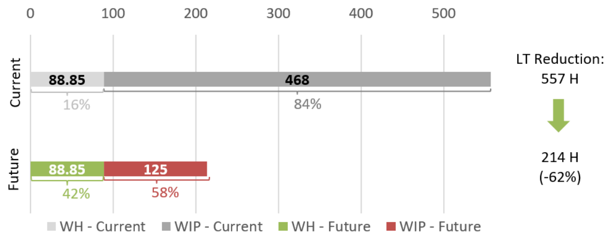


Figure 9: LT, WH and WIP reduction for the MDG

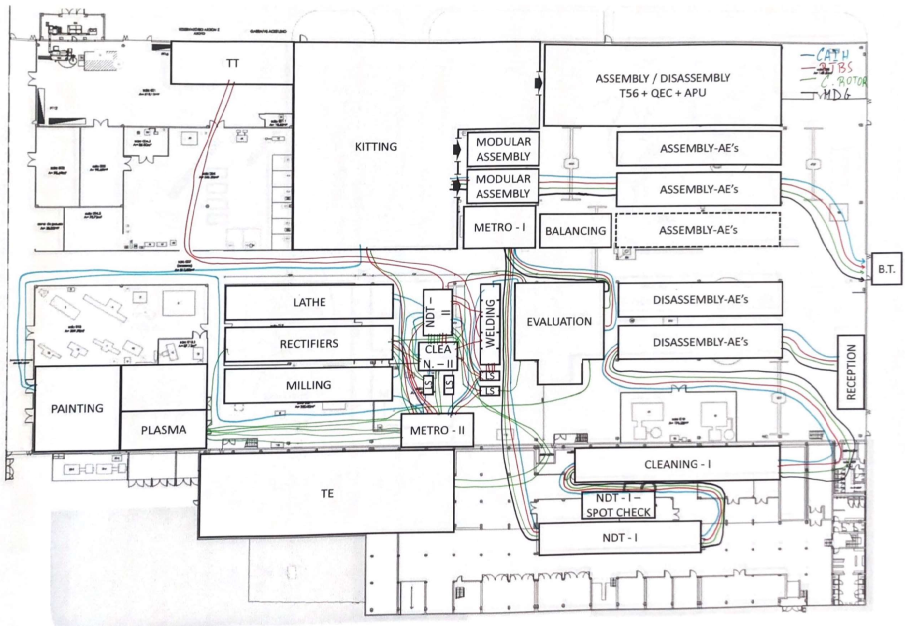


Figure 10: Spaghetti Diagram of the future state

in the middle to feed each station. For this reason, the new layout results in a spaghetti diagram where the only place with high density flow lines is in the repair area where the entire counter-flows were inspected.

Regarding the evaluation area, figure 11 displays the layout proposed with the resulting necessary movements of the evaluators. The planning of the evaluation area starts with the inspection that the area needs to accomodate 4 AE engines at the same time, according to the lead times of the preliminary activities.

The reception area is now organized and segmented by engine. Moreover, for the reception of

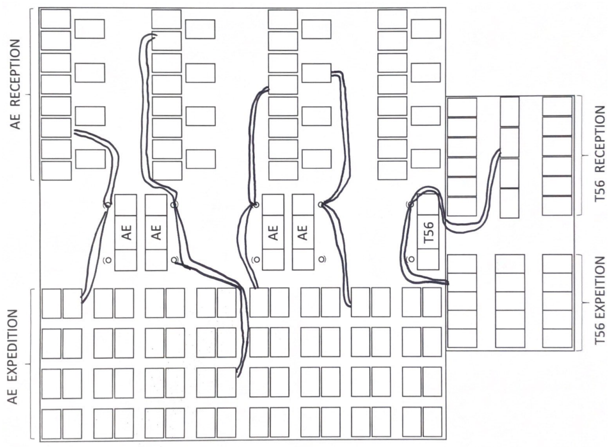


Figure 11: Future layout of the evaluation

each engine it is made two differrent lines, for the critical and non-critical parts, with the objective to enhance the visual management of the stations.

Furthermore, the red lines of figure 6 are now extinguished with the employment of additional measuring devices inherent to each workbench. It is also observable that the area can accomodate up to 10 evaluators wihtout additional implementation costs, in case the market demand increases or the current worforce is not able to adress the workload.

As a final note, the improvements result in the reduction of the waiting waste concerning the time the operators take to find parts in the reception and a reduction in the avoidable motion waste with the allocation of easy to access measuring devices to all evaluators.

5.4. Finantial Gains Analysis

In terms of time spent per process and distances traveled inside the plant by the components, it is clear that the improvements are advantageous. However, the implemantation of the improvements comes with a cost structure which is segmented in three major distinct areas related to the three new centers of cleaning, NDT and metrology.

Concerning the cleaning station, the initial investment is residual, since there is a functional cleaning machine in storage which is currently not being used. The inherent costs of this implementation include the formation of the workforce to be legally able to operate the machine and its periodic maintenance. Even though some cleaning processes may take around 1 hour, the actual labour is only endured in the first minutes of the activity to set the machine. For this reason, the addition of an operator exclusive to the second cleaning center is not necessary, since the current repair workforce can perform this task in parallel.

Regarding the NDT center, there is also a functional cabine not being used, hence the initial investment is residual. In this segment, the costs are due to the maintenance, calibration of the devices, technical formation and employment of a new technician exclusive to this operation. In this case the NDT associated labour is extensive thus the additional operator is required full-time.

Concerning the metrology area, it is proposed to employ a robotic measuring arm system which the company has already acquired in previous years. The cost structure of this segment is constituted by the maintenance, calibration, formation and an additional operator responsible for the metrology exclusively at ful-time.

Table 5.4 summarizes the related costs of implementation, where the initial investments concern the technical formation and the monthly cost concerns maintenance and calibration. The salary values are not displayed.

Table 1: Costs of implementation (Euros)

	Ini. Invest.	Monthly Cost
Cleaning	2500	0
NDT	3000	242.20
Metrology	2800	0
TOTAL	**8300**	**242.20**

Besides these second centers, the multiple lines of assembly and disassembly also come with additional costs with the main contribution being the additional workforce needed for the operations and an additional cost of necessary tooling. The additional line of disassembly is planned to require 5 technicians and the assembly line is expected to require 6 technicians.

Nonetheless, the increase in volume of engines is done gradually, hence the allocation of workforce is set to follow the revenues curve in order to maximize the resources employment. This factor is important so that the plant is always using the resources in the most efficient way throughout the years, while keeping its costs to a minimum. Table 5.4 displays the allocation of the employees according to the increased volume. It should be noted that the increased number of engines is in relation to the present year.

In figure 12 the green curve represents the expected increased annual revenues regarding the forecast engine volume and the red curve displays the percentage of the additional costs in function of the shift in revenues.

Due to the enterprise politics, it is not explicit the cost of an employee, however the sum of all the costs including salaries, initial investment, technical formation and equipment maintenance and calibration, is displayed as a percentage of the total shift in

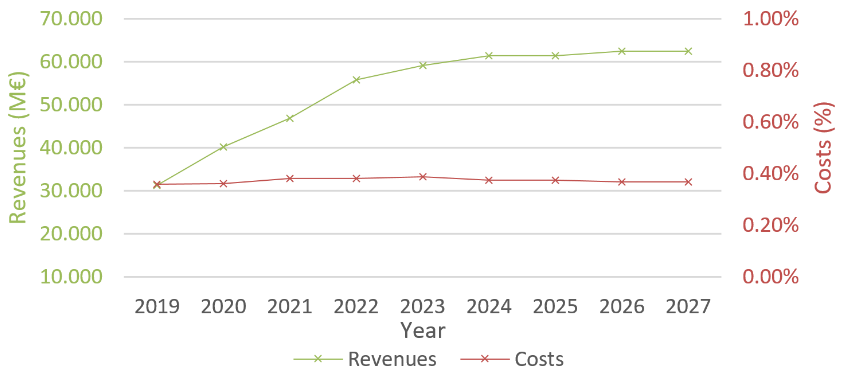


Figure 12: Revenues and costs curve according to the annual forecast

Table 2: Allocation of technicians according to engine forecast

	Eng. Vol.	Assemb. Tech.	Disassemb. Tech.
2019	28	2	2
2021	42	4	4
2023	53	6	5
2025	55	6	5
2027	56	6	5

revenues. The costs of implementation and workforce are observed to be considerably lower compared with the increased gains in revenues. With the complete population of the stations and the plant working at full capacity (expected in the year of 2027), the increase in revenues equals 61 million euros with an increased cost in the order of magnitude of 0.1%.

With this being said, the achieved plant setup enables an increased capacity of engine volume with a residual inherent cost. Moreover, the plant flexibility is reflected in the control of the costs according to the market demand without jeopardizing the quality of the operation.

6. Conclusions

The present paper employs Lean tools to first diagnose the issues of the enterprise when an increased client demand is forecast and used of the same Lean tools to plan the future state of the plant. With the Takt Time settled, it is concluded that the improvements enable the possibility for the company to fulfill the orders of the increased demand.

Furthermore, the improvements were carefully planned to ensure the plant runs smoothly during both higher or lower work volumes. This is due to the fact that besides the increased capacity enabled by additional centers with additional machinery, the proposed solutions increase the multifunctionality of the workers. For this reason, even though the future state is planned and has not yet been experimented, the company can be confident that the improvements hereby proposed provide a considerably better preparation regarding the client demand fluctuation at an almost residual cost.

To summarize, the following points regard the final achievements:

- Layout proposal for a functional future plant state;
- Reduction on the TAT from 75 to 51 days to assure the client demand;
- Aggregated value to the company with high gains in terms of revenues with low investment costs.

With this being said, the application of the Lean methodology tooling has enabled the MRO to effectively reorganize its maintenance line to comply with the market demand precondition.

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