Original research article

UAVs' efficient assembly: Lean Manufacturing implementation in an UAVs' Assembly Company

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ABSTRACT

In the UAV (often called drones) industry a zero defects culture is required. However, process improvement through the DMAIC lean methodology has not been widely studied in this industry. This paper examines how to solve the increasing quality problems of a small drones' assembly company. A circular DMAIC methodology was used as an adaptation of the DMAIC methodology. Principal results obtained demonstrate a reduction of the lead time and an increment in the leanness degree level from 23% to 60%. Multifunctional worker rate increased from 75% to 83% and motion waste was reduced almost in a 50%. Line balancing and Simulation were applied.

Abbreviations and symbols

UAV	Unmanned Aerial Vehicle	VOC	Voice of Customer
VTOL Drone	Vertical Takeoff and Land (VTOL) drone	CTQ	Critical to Quality
MTM	Method-Time Measurement	KPI	Key performance indicator
QFD	Quality Function Deployment	θ_{Str}	Structural degree
VSM	Value Stream Mapping	θ_{Org}	Organizational degree
SMED	Single minute exchange of die	θ_{Res}	Involvement degree
PDCA	Quality improvement methodology	MfWR	Multi-functional Worker Rate
DMAIC	Quality improvements six sigma methodology	RPW	Ranked Positional Weight
SIPOC	Process mapping methodology, Supplier, Input, Process, Output, Control	SAPS	Acronym for the company's name

ARTICLE INFO

Article history:

Received August 25, 2020

Revised December 1, 2020

Accepted December 3, 2020

Published online December 10, 2020

Keywords:

UAV;
DMAIC;
Shojinka;
VOC;
Ranked Positional Weight

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1. Introduction

Evolutionary changes are happening, with human population and consequently in industries. One of these changes is the introduction of unmanned ae-

rial vehicles (UAV's), also known as drones, into multiple areas. Although, the use of UAVs started in the mid-eighties [1] enhancements in safety, performance, reliability, and affordability have ensured this product's maturity [2] and positioning in the

marketplace. The use of drones has demonstrated several advantages for multiple industries. Maghazei and Netland [3] studied the advantages of drones' introduction into diverse industry sectors. Cost savings, task speed and efficient collection of data were some of the multiple advantages industries were experiencing [3]. Furthermore, the Federal Aviation Administration has accounted in 2019, only in the United States, 1,548,816 registered drones. Commercial drones represented the 28% of this number [4].

The present study was developed on SAPS, an UAVs' assembly company. This company designs and produces two kinds of UAVs, both VTOL drone types. The product which will be studied represents 62% of SAPS' total sales. Nowadays, several complaints have been received mainly related to quality issues. This situation has raised production costs. Considering Lean manufacturing implementation results in other industry sectors it will be used to achieve the objective of this study.

Lean manufacturing was a term coined by the MIT from the Toyota Production system which centers on the elimination of the various forms of waste through the implementation of improvement activities [5]. A great quantity of research has been done referring to Lean implementation focused on manufacturing industries. Gupta et al, studied the application of six sigma in an Indian tire-manufacturing company. Main results conducted to reduce process variation and enhance process capability [6]. Same results were obtained by researchers Meena, et al. with their study in an Indian automotive part manufacturing company in which the reduction of defects during automotive parts production was the main advantage gained [7]. Gazoli de Oliveira and da Rocha Junior explored the advantages gained by a medium-size enterprise through lean manufacturing implementation [8]. Analysis and reconfiguration of activities performed during the setup time and the use of lean tools as the spaghetti diagram and Kaizen activities contribute to productivity and processes improvement [8]. Herlambang and Hidayati used takt time and balancing to improve work standardization and productivity in a steel industry. [9] Klasnja, et al. optimized a cable harness production system by the identification of non-value-activities and a reconfiguration of working stations based on takt time and cycle time analysis [10] Singh and Rathi presented a literature review of Lean Six Sigma implementation in the manufacturing, health care, financial and education sector [11] Principal findings showed that waste and defects reduction, minimization of costs and high quality products development were the

main advantages gained by these sectors [11]. Moreover, Durakovic, et al. analyzed diverse publications and found that principal benefits gained by industries with the introduction of lean manufacturing techniques are the reduction of any form of waste as excess of inventory, waste of time and waste of product. [12]. As Durakovic et al. recognizes challenges exist in the implementation of lean manufacturing but recognize it is useful and applicable in any sector or service [12]. However, according to the lean review by Jasti and Kodali the percentage of research contributions of lean production in the aerospace sector is only 1,46% [13].

Although there is a lack of research about the study of drones' manufacturing and lean manufacturing implementation, drones have proved their ability to cope and be a support in Lean manufacturing implementation projects. Ersoz, et al. [14] incorporated the use of UAVs in the construction sector and proved their effectiveness to support continuous improvement, visual control (Jidoka) and sharing of knowledge activity between departments (Worker Involvement), which are some of the lean principles. Tezel and Aziz [15] connected the gap between the utilization of drones and the principles of lean construction. They concluded demonstrating a reduction of mistakes and non-value-added activities. Romero et al. [16] presented drones in their lean study, to eliminate motion waste by using them on searching, picking and delivery activities.

The analysis of these previous research confirms lean manufacturing have been applied in a diverse range of industries. This analysis also shows almost no studies were developed in non-continues drone assembly processes. The common characteristic of these studies is the reduction of cycle time and defects, productivity increase and unification and standardization of processes as the principal improvements gained in all sectors.

Although, a lot of research has been done considering lean implementation, this study centers on the application of Lean Manufacturing philosophy through an improvement of the DMAIC methodology in a drones' assembly company. The main goal of this research is the implementation of lean tools to increase the company's capacity through the analysis of takt time and current processes.

This paper is organized as follows: The first section gives an overview of the metrics established, measurements and results gathered, and implementation of lean tools undertaken. Through the DMAIC methodology baseline results are displayed and compared to the final leanness level achieved. A

duction of 66% of cycle time and an increase from 23% to 60% in the company's leanness degree, leanness metric which measures organizational, structural and involvement company's dimensions, are some of the principal improvements obtained. In the second section the adaptation of the DMAIC methodology used is described considering our case of study. The third section introduces the practical case study with Lean Manufacturing implementation into SAPS. Section 4 shows the discussion considering previous studies and results gathered and last, section 5 summarizes the principal results obtained after Lean Manufacturing implementation.

2. Methodology

To analyze the application of lean and six sigma tools and principles, the DMAIC methodology was selected. DMAIC methodology was selected considering lean implementation projects have shown to have great impact when structured through PDCA and DMAIC methodologies [17]. Sokovic et al. [18] showed a clear relationship between PDCA and DMAIC, as DMAIC is a variant of the PDCA method. Moreover, "DMAIC methodology is used in many aerospace companies as their preferred method for process improvement" [19].

The DMAIC methodology is a well-established five sequence step (define, measure, analyze, improve and control) that seeks to reduce variability by eliminating defects in processes directly connected with customer satisfaction [20].

Typically, the DMAIC methodology follows step by step the improvement cycle. This cycle requires completing each of the five stages before moving to

the next one [21] [22]. Holly Ott [21] proposes a Six sigma road map and problem-solving strategy where the DMAIC cycle breaks into a funnel. In the Define stage, the relationship between customer needs (CTQ's) and process parameters are established, defining the relating $Y=f(x)$ function [21]. Moving through the improvement cycle, Measure, Analyze and Implement stages are executed to end up in the Control phase where process controls strategies are to be defined [21].

However, when implementing an improvement project, the unified structure of Lean Six Sigma requires a more flexible framework based on the PDCA and the DMAIC cycle [20]. The success of a project implementation relies on the synergic integration of the flexible framework. This paper adapts the DMAIC methodology and Holly Ott's [21] funnel to propose a nonlinear implementation roadmap to the Lean Six Sigma problem solving approach. The following modifications were made (Figure 1).

As a first step, the define phase helped to understand the VOC and relate customer requirements to process parameters [23]. Documenting information tools and high-level process analysis support the purposes of this phase [23]. To define the problem a SIPOC diagram was used to establish a high-level picture of the drones' manufacturing process [23]. Customer interviews and benchmarking were used to understand the VOC during the Define phase. The Critical to Quality Tree, was applied to create metrics considering the customer's product perspective. During this phase, historic data and process measurement were used to obtain the project's baseline. A smaller PDCA cycle was generated within this stage. An initial analysis of financial and business results

Figure 1. DMAIC Methodology adaptation for project execution

took place to create the project roadmap.

With an established project charter, during the measure phase, process mapping and data collection were required to define process capability [24]. The As-is process map was used to understand the complete process description. Key performance indicators (KPI's) and problem baseline were outlined. This required continuous data gathering and analysis.

During the Analyze phase measuring continued to confirm the vital few parameters that were determinant for the project success. A deep measurement and data analysis to support initial quick wins implementations was performed [25]. Quick wins helped to redefine the project roadmap and baseline and establish an initial control plan. Critical system parameters were validated or reformulated to continue major process improvement implementation.

Moving on, during the Improve phase solutions were created and implemented [26]. Creative, cheaper, and faster solutions are preferred from a Lean

perspective [27]. 5S and the Kanban system lean tools were implemented. As a complement, discrete events simulation and line balancing were applied during this phase. Defined KPI's were reviewed and analyzed again to assess the level of success gained with the implementation of lean six sigma principles [28].

Finally, in the control phase new data collection and validation of data was done. Initial control plans developed during quick wins implementations were reviewed and validated. This phase ensured improvements will stay in the long term. Procedures were enlisted to maintain and standardize processes [29]. Moreover, Nelson, [30] proposed the implementation of control plans to monitor the process. This was a requirement to prevent the problem studied reappear [30]. Table 1 presents a summary of the methodology used during this study with its deliverables and considerations.

Table 1. DMAIC Methodology adaptation for project execution

	DMAIC Activities required	Deliverable	Consideration
DEFINE	*Defin *Measure *Analyze	* SIPOC diagram * CTQ tree diagram *Historic information analysis * Initial baseline assessment * Project charter	* Initial estimate of project impact from historic data (initial evaluation) * Initial process testing/evaluation
MEASURE	*Measure *Analyze	*KPI Definition from CTQ *Leanness degree *Takt time	*Process measurement * Process testing/evaluation
ANALYZE	*Measure *Analyze *Implement *Control	* Pareto diagram * Cause and Effect diagram *Quick wins implementation and analysis *Project charter objectives redefinition from process testing	* Project impact redefinition * Quick wins implementation
IMPLEMENT	*(re)Defin *Measure *Analyze	* 5S * Kanban system *Ranked positional weight heuristic application for line balancing *Discrete event simulation	* Major improvements tested and evaluated * Project impact analysis
CONTROL	*Measure *Analyze	* Process monitoring plan	* Final project evaluation * Future process improvement plan

3. Results: Industry application UAV's assembly

3.1 Define

During the first phase a SIPOC diagram (Supplier, Inputs, Processes, Outputs and Customers) was created based on the high-level process map of SAPS' UAV's assembly process.

SAPS' UAV's assembly process is divided into eight different subprocesses.

- Fuselage sub assembly process
- Electronic sub assembly process
- Wings sub assembly process
- Wings' motors subassemblies process
- Landing gear sub assembly process
- Tail sub assembly process
- UAV's quality check process
- Customer's training process

The SIPOC approach helped to understand product requirements and process capabilities relationships to define the project's scope [31].

Once an overview of the production process was finished a detailed understanding of internal and external customers' requirements was conducted. The VOC was established based on customer after sales

surveys [23]. Just under two thirds (63%) of the received complaints between February and December 2019, were related to a flight issue during one of the first three flights. Figure 2 shows a distribution of flight failure causes.

Further examinations on this historical data showed that the 57% of flight failures classified as quality issues were related to missing components, missing calibration steps and incomplete quality checks. The most striking result to emerge from this data is that software quality issues and operators training are also production department responsibility. Surprisingly, the production plan does not include software quality tests as part of the production schedule. Test activity is crucial to decrease the chance of software failures.

Moreover, pilots' operation knowledge is not evaluated, which makes it difficult to establish an indicator of operators' training level. These results offer compelling evidence of poor-quality management activities.

These results thus need to be interpreted with attention to understand the relationship between customer's needs with technical requirements. The CTQ Tree presented in Figure 3. was constructed based on the VOC [32]. Drivers were defined based on flight failures data presented on Figure 2 and target values were gathered through the production department.

UAVs' flight failures causes

■ Quality issues ■ Operators training ■ Software

Figure 2. Percentages of UAVs' flight failures causes

To define an initial baseline assessment the process metrics gathered in the CTQ tree were mea-

sured between December 2019 and February 2020. Table 2 and Table 3 show these results:

Figure 3. Critical to Quality Tree

Table 2. Percentages of completed components per subassembly

Percentages of completed components/subassembly					
Subassembly	Wings	Fuselage	Electronic subassembly	Tail	Landing gear
Compliance percentage	88%	82%	86%	85%	100%

Table 3. CTQ Tree measured metrics

	Nº of completed calibrations	Nº of completed flight test	Nº of software hours tests/month	Minimum grade required to pass the online course
Required	57	96	64	90
Accomplished	40	84	20	57
Compliance percentage	70%	88%	31%	63%

At the same time, between December 2019 and February 2020 several complaints were received. Table 4 shows complaints distribution.

These baseline measurements displayed several opportunities. Although most metrics were above 80%, quality requirements do not admit anything less than a 100%. UAVs' performance is affected by any missing component or flight test not properly executed.

These values correlate fairly well with customers' complaints and further support the idea that processes were not being properly conducted.

A Project Charter was prepared in accordance with initial measurements. A projection of 40% cycle time reduction and a saving of USD1000/UVA was forecasted. The prognosis was defined based on the elimination of non-value added activities and the elimination of parts replacement due to accidents. An increase in productivity and a downtime reduction is also expected.

3.2 Measure

In order to follow lean implementations, a baseline of the Leanness degree developed by Amrani et al. [17] was measured. Amrani, et al. [17] described the Leanness degree as a key indicator which can be used to evaluate how lean a company is. It was developed as a theoretical measurement to be applied in aeronautical companies. The equation measures three parameters: structural, organizational and involvement degrees [17]. The structural degree evaluates the workshop's physical configuration [17]. The organizational degree measures the leanness dynamic dimension of the company. This component helps to understand the ability to comply with demand [17]. The involvement degree measures the agility of human and technical components of a company [17].

The Leanness degree equation was used considering each parameter objective as initially proposed by Amrani, et al. Equation 1 shows the leanness degree as the multiplication of the three key parameters.

$$LeannessDegree = \theta_{str} * \theta_{org} * \theta_{res} \quad (1)$$

However Amrani, et al. [17], does not define a mathematical approach to evaluate each parameter degree. In an attempt to measure the leanness, we propose specific measurement equations for each parameter to obtain a final leanness value. This follows the main objective proposed by Amrani, et al. [17].

The main objective of the structural degree, as proposed by Amrani, is the evaluation of transportation time considering processes layout configuration [17]. To assess the structural degree, a non-motion waste measurement was defined as presented in equation 2.

$$NonMotionWaste = \frac{ActivitiesWithoutMovements}{TotalNumberOfActivities} * 100 \quad (2)$$

The non-motion waste formula captures the fraction of activities from SAPS' assembly process that are performed without unnecessary movements. An As-is process map was developed to understand and identify the UAV's process activities [33]. In addition, a Spaghetti diagram was constructed to evaluate the distance covered during non-value-added activities.

After the structural degree was measured the organizational level of the leanness degree was analyzed. In order to evaluate this dimension, the process cycle efficiency indicator, presented in equation 3, was used as it compares the amount of added-value time to the total lead time [34]. To identify the value-added time a Time Series Format adaption was used [35]. This tool was used instead of the VSM as, according to Dal Forno et al., limitations presented in complex processes and products are drawbacks of the VSM [36]. Lead time was obtained through a time study. Three production cycles were measured considering the General Electric Company's Time Study Manual [37].

$$ProcessCycleEfficiency = \frac{ValueAddedTime}{TotalLeadTime} * 100 \quad (3)$$

$$ProcessCycleEfficiency = \frac{56h}{105h} * 100 = 53\% \quad (4)$$

Table 4. Customers complaints between December and March 2020

Complaints	Flight failures	Training complaints	Delivery time	Quality brochure	Esthetic	Lack of accessories	Warranty	Usage restrictions
Frequency	5	5	4	3	1	1	1	1

The last component is the organizational degree. Amrani, et al. suggested as an indicator of this dimension the number of multifunctional workers [17]. Multifunctionality of workers was studied by Monden in his book *Toyota Production System*. He proposed a Multi-functional Worker Rate (MfWR) equation to evaluate Shojinka [5].

$$MfWR = \frac{\sum_{n=1}^n (\text{numberProcessesEachWorkerMastered})}{\text{TotalNumberProcessesShop} * n} * 100 \quad (5)$$

The Multi-functional Worker Rate evaluates the degree of knowledge workers have of the activities needed to assemble an UAV. In this equation n represents the total number of workers at the shop [5]. The UAV's process assembly requires two workers to complete the eight different activities.

$$MfWR = \frac{8 + 4}{8 * 2} * 100 = 75\% \quad (6)$$

Once the three parameters were measured the Leanness degree was obtained:

$$\text{LeannessDegree} = 59\% * 53\% * 75\% \quad (7)$$

These measurements reveal that degree of leanness is poor. A desired level is set at 80%. This objective was defined considering non-motion waste and multi-functional worker optimum values of 95% [5] and according to Koenigsaecker's World-class Japanese firms [38] operate with a 90% value-added lead time.

Finally, takt time was analyzed as it synchronizes production with demand [39]. This indicator helps to measure the difference between the current production rate with the rate of demand [40].

Takt time can be calculated considering the following formula:

$$TaktTime = \frac{\text{AvailableProductionTime}}{\text{Demand}} \quad (8)$$

In order to use this formula, monthly demand is needed. Two demand forecasting methods were used considering SAPS company has only a year in the marketplace with VTOL drones.

Bass Diffusion [41] and QNAP [42] models have proved effectiveness with the forecast of demand for

new products. The Bass model was used considering the lack of information about UAVs in Latin America's countries. The robustness of this model is proven in Bass book: *A New Product Growth Model for Consumer Durables* [41], which demonstrates efficacy with any kind of product, including new technologies [43].

$$S(t) = [p + (\frac{q}{m}) * N(t-1)] * [m - N(t-1)] \quad (9)$$

The Bass Model nonlinear equation 9 requires two important parameters: p and q . P is the rate at which innovators will acquire the new product and q the rate of imitators, or consumers who will buy influenced by innovators [41].

Software Minitab 2019 was used to solve the nonlinear equation in order to get p and q parameters. Taking these results, two drones per month demand was forecasted. Moreover, the QNAP forecasting method [42] was chosen considering it can be applied for a wide variety of products. Demand forecasting was obtained through the following equation:

$$Q = N * A * P \quad (10)$$

This model relies on three parameters: N explains the number of expected potential customers, A the fraction of customers for which the product is available and finally P the probability that a product can be purchased if it is available [42]. N and A parameters were calculated based on the company's target market and P through the results of 110 surveys [44]. A target population of 347 companies was considered. This population was taken considering the company's sales department information of the actual market. A forecasted value of two drones per month was obtained. This confirms previous findings with the Bass Model forecast.

Takt time was calculated considering the available production time and the forecasted demand.

$$\begin{aligned} TaktTime &= \frac{96\text{hours/month}}{2\text{drones/month}} = \\ &= 48\text{hours/drone} = 6\text{days} \end{aligned} \quad (11)$$

The takt time of 6 days is less than the cycle time of 15 days (from production records it was possible to determine that a drone is delivered to a customer

in an average of 15 days). These findings show additional evidence of SAPS' capacity issues.

3.3 Analyze

Complaints were analyzed as they directly relate to the VOC. A Pareto diagram helped to visually classify the complaints presented in Table 4 that resulted in quality issues. The identification of these vital few causes succor to define solutions that will contribute to the overall process improvement. Flight failures and training complaints were pinpoint as the principal causes representing together the 46% of complaints.

Training complaints were not analyzed in depth because during the Define phase these complaints were identified as part of flight failures.

Figure 4 presents the Cause and Effect diagram which was used to analyze flight failures. Cause and Effect diagram is a validated tool which helps to identify and understand all the possible causes of a specific problem [45].

The different causes were gathered through group meetings with the employees from the production department. A mind mapping strategy was

used through brainstorming in order to compare and share ideas. Brainstorming motivated people to propose ideas without feeling judgment [46].

Once all ideas were shared, compared, and analyzed a prioritization matrix was used in order to highlight the principal ones and classify them as potential causes.

The GUT (Gravity, Urgency and Tendency) matrix was implemented as it evaluates objectively these 3 parameters with a 5 points scale in which 1 corresponds to the minimum gravity, urgency and trend respectively and 5 the maximum [47]. Each cause was evaluated by the production department. Causes with the main GUT values were highlighted in red. Results are presented in Figure 4.

Root cause analysis revealed that multiple problems derived by main causes could be tackled by implementing some initial solutions. Flight failure causes were classified and solutions were proposed as quick wins. Quick wins can provide a justification to the investment and increase the interest to continue with a lean project [48]. Moreover, they can motivate the workforce as initial improvements involve workers with system transformation. Table 5 presents the causes tackled and the solutions provided during

Figure 4. Ishikawa diagram

Table 5. Quick wins implemented considering determined causes in the Cause and Effect Diagram

Causes	Quick wins
Lack of standardized processes	UAV's assembly process manual and training
Lack of communication	Process unification App between sales and production departments.
Lack of quality control procedures	Quality control sheets
Lack of quality control of components	
Not defined measurement parameters for flight and calibration tests	
Pilots not 100% trained	Pilots' online training

this phase.

Initial quick wins implementation were executed and measured during March 2020 obtaining important initial improvements:

UAV's assembly process manual implementation and training; made possible the increase of multi-functional worker rate, one of the leanness degree parameters.

$$MFWR = \frac{8+6}{8*2} * 100 = 87\% \quad (12)$$

Results showed both workers were able to complete the six sub assembly processes. This agile implementation was possible as assembly principles were already known by both operators. Key process activities as pilots' training and UAV's quality check activities are areas in which the company needs to continue working to improve Multi-Functional Worker Rate.

Communication process unification software application:

improved communication between sales and production departments. This helped to reduce production planification issues, organize production activities and gain time to perform quality control activities.

Quality control sheets:

Quality control sheets is a tool used in lean companies to minimize the risk of errors and improve data collection [49]. A detailed checklist containing the UAV's specific list of key process activities for final quality control was implemented. The result of

this implementation is shown in Table 6. The four metrics established in the Define phase through the Quality Tree diagram were measured.

Pilots' training:

An online training course was developed dividing lessons into required knowledge sections. Tests for each section helped the production department to assess the pilot's knowledge level and recognize the areas in which a training reinforce was needed. The incorporation of the online training course has decreased process cycle time from 105 hours to 56 hours. After these improvements, metrics, shown in Table 7, have reached their target level.

During the first pilot study with the new process conditions; the introduction of Quality control sheets and UAV's process manual, the cycle time showed a reduction from 15 to 8 days. Once these new measurements were gathered the Project Charter projection was updated. From a 40% of cycle time reduction as an initial estimate, it was possible to understand that a 55% time reduction was plausible. Saving projection was not changed from the USD 1000/UVA.

3.4 Improve

Once quick wins were in place, we then started the 5'S lean tool and a Kanban system implementation. At this point the 5'S tool was implemented following the steps proposed by Monden [5] in his book Toyota Production System. An initial audit was carried out using a 50 questions questionnaire design by Ho [50] to assess the accomplishment level of each 5'S activity.

During the Sort phase necessary things were sep-

Table 6. Percentages of completed components per subassembly after the quick wins' implementation

Percentages of completed components/subassembly					
Subassembly	Wing	Fuselage	Electronic subassembly	Tail	Landing gear
Compliance percentage	100%	100%	100%	100%	100%

Table 7. CTQ Metrics measured after quick wins' implementation

	Nº of completed calibrations	Nº completed flight test	Minimum grade required to pass the online course
Required	57	96	90
Accomplished	57	96	92
Compliance percentage	100%	100%	100%

arated from the unnecessary ones [5]. A selection criterion was developed to decide which items correspond to the unnecessary category [5]. A Pareto diagram was implemented to categorize UAVs assembly process tools and machines measuring usage frequency. Tools and machines corresponding to most frequent activities were selected to stay near the workstation.

A specific location for each machine, tool and component of the bill of materials was defined. Containers were prepared based on items sizes [5]. Label identification for each item included: name, code, quantity, and location. Information was registered in the company's software control system. Organization was done using Monden's [5] four steps approach. Figure 5 shows the implementation results.

As part of the Set in Order process, two different color baskets were used as withdrawal and production ordering kanbans [5]. Kanbans have the capacity to transform a push system into a pull system [5]. To implement all these changes a machine shuttle was acquired. Its reconfigurability, simplicity and flexibility support leanness principles [51]. Through 5S and Kanban system implementations, motion waste generated by searching and finding movements have almost disappeared. Non-motion waste has been recalculated presenting the following results.

$$Non - MotionWaste = \frac{198}{224} * 100 = 88\% \quad (13)$$

In order to improve Shine, Standardization and promote Sustain activities a 5S Map was defined with specified items' locations. Workforce 5S responsibilities that included promoting 5S culture, workspace cleaning and inventory control were established. A reward plan and a 5S implementation manual that included a detailed questionnaire to measure

5S accomplishment was developed.

Changes in the production process were noticeable, motion waste was drastically reduced and added-value time increased. With this improvement, process cycle efficiency was re-evaluated considering the new process cycle time of 56 hours.

$$ProcessCycleEfficiency = \frac{44h}{56h} * 100 = 78\% \quad (14)$$

Once lean measurement parameters were recalculated, the leanness degree presented a completely different level. The Leanness degree showed an increment from 23% to 60%.

$$LeannessDegree = 88\% * 78\% * 87\% = 60\% \quad (15)$$

Improvements showed drones production process will have a projection of a 7 days cycle time, with 5 days corresponding only to the assembly process. However, this cycle time reduction does not align with takt time.

In order to understand why process changes did not create the desired impact to meet demand rhythm a deeper analysis on job distribution among workers was performed. Currently the company counts with two operators in the production department. Each worker is assigned to specific activities required to assemble a UAV. Process observations showed that as soon as one employee finishes his assigned tasks, he moves to start with the production of a second unit. This disorganization of activities generates an increase in WIP and cycle time. Lean manufacturing philosophy promotes a one-at-a time manufacturing strategy to reduce inefficiency in production activities [51]. Line balancing is a lean practice which helps to

Figure 5. Set in Order of Tools and Machines

increase a company's efficiency [52] and adapts it to a pull system.

Ranked Positional Weight (RPW) is a heuristic method introduced by Helgeson and Birnie in 1961 [53] which aligns to line balancing objectives. It is based on the assignment of process tasks considering cycle times and precedence constraints. The heuristic assigns production activities to the worker based on tasks RPW values. Activities' process times are compared to takt time for assignment purposes [53]. The UAV's assembly process precedence diagram is displayed in Figure 6. It shows the 6 sub processes in their respective order.

This heuristic model revealed that two operation sets are to be aligned, each one assigned to one of the two workers. This solution represents the order in which activities should be performed. However, considering the multi-functional objective Workers 1 and 2 should have the knowledge to perform any set: Set 1 or Set 2.

- Set 1: Worker 1: Activities {1, 4, 5, 7}
- Set 2: Worker 2: Activities {2, 3, 6, 7}

Given that this was a preliminary attempt to modify the production process sequence a discrete events simulation was developed through Flexsim software. Simulation is a tool used to design and analyze new systems behavior which have not yet been implemented. It is used to propose changes and evaluate outcomes before a possible implementation [54]. Figure 7 presents a screenshot of the simulation developed through Flexsim software.

Findings from several simulation runs provided key insights of process behavior. Figure 8 shows workforce utilization percentage. A mean of 93% utilization proves task assignment solutions do not under or over utilize these resources. In addition, production time has been reduced by 66% showing cycle time could be 5 days. This creates spare time for software and physical product's quality improvement and fulfills the takt time of 6 days.

Figure 6. Diagram of precedence

Figure 7. Flexsim software RPW simulation

This gives SAPS a competitive advantage considering the 2 drones per month demand.

3.5 Control

The control phase helps to maintain the leanness level achieved [31]. Documenting and standardizing were the main activities executed. Sales and production communication policies were established along with poka yoke controls to ensure traceability of information. The UAV's assembly process manual developed during the Analyze phase was properly socialized and visual control were implemented in the production area.

To monitor compliance with policies, processes and standards, the use of an online application was carried out. At the beginning of each operation SMART objectives were created and monitored through a Box Score System. To include workforce ideas, the online application contains a brainstorming section. In this way opportunities were identified and considered through projects development [31].

4. Discussion

Results of this investigation demonstrated the correlation between Lean Manufacturing implementation and the increase in quality and optimization. As previous studies done in the aeronautical industry product complexity, quality focus and missing parts were some of the main lean inducers for this project [55].

The leanness degree was measure after improvements obtaining a 60% compared to the initial 23%. This result was derived from the reduction of almost 50% of motion waste, and an increase of multifunctional workers rate from 75% to 80%. These results fit with studies done in the aerospace sector in which

work standardization and multifunctional workers were the key advantages gained by this industry [56].

Simulation helped to gather a theoretical result which showed a 60% reduction in the process cycle time. This result has further strengthened the confidence in simulation as a key optimization tool when dealing with implementation limitations.

Contrary to the hypothesized association about lean manufacturing unique application into high-volume production industries [57] this study has shown it can be applied in a low volume, low repeatable industry. However, to obtain these results a VSM and DMAIC modification were used considering company's reality. Having carried out this study with a modified, non-linear DMAIC allowed a continuous implementation and ensured continuous improvement at each step. These implementations could be extrapolated into other studies in which lean tools need to adapt considering industries reality.

Tools such as VSM, Kaizen, Six Sigma [55] QFD, Kanban [56] SMED, Poka-yoke and 5S [57] have been identified as some of the principal lean tools in aeronautical studies. This research was able to follow best practices and implement most of them. In addition, the use of the leanness degree proposed by Amrani et al. as a theoretical formula and developed in a practical form contributes to the literature as it helps to measure an industry considering its workforce, organization, and structure level.

This paper can be used as reference to guide specific improvement projects as:

- It has been shown that is possible to adapt the lean system to unconventional and low volume production systems.
- The modified DMAIC cycle allowed a better adaptation to a rapid changing industry and enable a gradual change.

Figure 8. Simulation workers' utilization indicators

- The use of Simulation proved non-conventional tools are suitable in lean manufacturing implementation studies.
- The Leanness degree measurement can be used as a key performance indicator to measure a company's leanness level maturity and its evolution when implementing lean philosophy.

5. Conclusion

This work evidence that Lean Manufacturing can be implemented in small non-continuous production companies. Moreover, it has revealed that Lean Sigma tools must be adapted before implementing them. Project implementation was presented through an industry application at SAPS assembly UAVs' company. An adaptation for project execution purposes of the DMAIC methodology guided the complete implementation. This method represents an innovative alternative to the traditional DMAIC approach. It created a flexible environment that promoted continuous systematic measurements. Data analysis was continuously performed throughout all the stages. The most relevant result to emerge from this systematic revision was the possibility to continuously adjust KPI's and objectives.

Problem definition was stated through a SIPOC, Critical to Quality Tree Diagram and initial measurements. Takt time and the Leanness degree evaluation proposed by Amrani, et al. [27] was used to understand the company's leanness performance level. The key advantage of the Leanness degree evaluation is that it allows to objectively evaluate the continuous improvement process.

A cause and effect diagram was incorporated during the Analyze phase. Main causes of flight failures which resulted in customer's complaints were tackled during this phase. Tables 6 and 7 show metrics improvements after Quick wins implementation.

From the results obtained in initial implementations it was possible to conduct 5'S and Kanban deployment. Results showed an increase in the process capacity but optimal production level was not reached to meet demand. The Ranked Positional Weight (RPW) heuristics was integrated to perform deeper analysis of process configuration. Unfortunately, we were unable to implement the RPW results due to the pandemic. Investigations into this area are still in progress and seem likely to confirm a plausible 5 day cycle time.

However, further analysis is recommended to evaluate new possible production configurations. Initial simulation runs showed that the company can as-

semble up to 8 drones a month with the installed capacity. An independent flight test department could be needed.

These results offer compelling evidence for the implementation of Lean tools as an optimization process in small production companies. Lean Manufacturing philosophy has improved culture and operational level.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

- [1] V. Prisacariu, "The history and the evolution of UAVs from the beginning till the 70s," *J. of Defense Resources Management*, vol. 8, no. 1, pp. 181-189, Aug. 2017.
- [2] Z. Liu, Z. Li, B. Liu, X. Fu, I. Raptis, and K. Ren, "Rise of mini-drones: Applications and issues," in *Proc. 2015 Workshop on Privacy-Aware Mobile Computing*, Jun. 2015, pp. 7-12, doi: 10.1145/2757302.2757303.
- [3] O. Maghazei and T. Netland, "Drones in manufacturing: exploring opportunities for research and practice," in *J. Manufacturing Technology Management*, Sept. 2019. [Online]. Available: <https://www.emerald.com/insight/content/doi/10.1108/JMTM-03-2019-0099/full/html>
- [4] Federal Aviation Administration. "UAS by the Numbers". Federal Aviation Administration. https://www.faa.gov/uas/resources/by_the_numbers/ (accessed Feb. 22, 2020)
- [5] Y. Monden, *Toyota Production System*. New York, NY, USA: CRC Press, 2012.
- [6] V. Gupta, R. Jain, M.L. Meena, and G.S. Dangayach, "Six-sigma application in tire-manufacturing company: a case study," *J. of Industrial Eng. Int.*, vol. 14, no. 3, pp. 511-520, , Sept. 2017, doi: 10.1007/s40092-017-0234-6.
- [7] M.L. Meena, R. Jain, P. Kumar, S. Gupta, and G. Dangayach, "Process improvement in an Indian automotive part manufacturing company: a case study," *Int. J. of Productiv. and Qual. Manage.*, vol. 23, no.4, pp. 524-551, Mar. 2018, doi: 10.1504/IJPQM.2018.090263.
- [8] A.L. Gazoli de Oliveira, and W.R. da Rocha, (2019). "Productivity improvement through the implementation of lean manufacturing in a medium-sized furniture industry: a case study," *South African J. of Ind. Eng.*, vol. 30, no. 4, pp.172-188, Dec. 2019, doi: 10.7166/30-4-2112.
- [9] A. Herlambang, and J. Hidayati, "Strategy and policy for increasing work productivity of operators in the steel industry through work improvement with lean method," in *IOP Conference Series: Materials Science and Eng.*, Medan City North Sumatera, Indonesia, 2019, vol. 505, no. 1, doi: 0.1088/1757-899X/505/1/012074
- [10] N. Klačnja, N. Sremčev, D. Vukelić, N. Simeunović, and M. Lazarević, "Optimization of Cable Harness Assembly Systems Based on Lean Concept Application," *Int. J. of Indust. Eng. and Manag.*, vol. 10, no. 1, pp. 115-123, 2019, doi: 10.24867/IJIE-2019-1-115.
- [11] M. Singh, and R. Rathi, "A structured review of Lean Six Sigma in various industrial sectors", *Int. J. of Lean Six Sigma*, vol. 10, no. 2, pp. 622-664. May 2019. doi: 10.1108/IJLSS-03-2018-0018

- [12] B. Durakovic, R. Demir, K. Abat, and C. Emek, "Lean manufacturing: Trends and implementation issues," *Periodicals of Eng. and Natural Sciences*, vol. 6, no. 1, pp. 130-143, Jun. 2018, doi: 10.21533/pen.v6i1.45
- [13] N.V.K. Jasti, and R. Kodali, "Lean Production: Literature Review and Trends," *Int. J. Production Research*, vol. 53, no.3, pp. 867-885, Jul. 2014, doi:10.1080/00207543.2014.937508.
- [14] A.B. Ersoz, O. Pekcan, and O.B. Tokdemir, "Lean Project Management using Unmanned Aerial Vehicles," *Tamap J. of Engineering*, vol. 65, Feb. 2019, doi: 10.29371/2018.3.65.
- [15] A. Tezel, Z. Aziz, "From conventional to IT based visual management: a conceptual discussion for lean construction," in *J. of information technology in construction (ITcon)*, Oct. 2017. [Online]. Available: <https://www.itcon.org/2017/12>
- [16] D. Romero, P. Gaiardelli, D. Powell, T. Wuest and M. Thürer, (2018, August). "Digital Lean cyber-physical production systems: the emergence of digital Lean manufacturing and the significance of digital waste," in *IFIP Int. Conf. on Advances in Production Management Syst.*, I. Moon, G. Lee, J. Park, D. Kiritsis, G. von Cieminski, Eds. Aug. 2018, pp. 11-20.
- [17] A. Amrani, Y. Ducq, and C. Goetz, "Analyzing the Lean Manufacturing Challenges to Sustain Flexible Aeronautic Industry," presented at the 6th Int. Conf. on Information Syst., Logistics and Supply Chain ILS, Bordeaux, France, Jun. 1-4, 2016.
- [18] M. Sokovic, D. Pavletic, and K. Pipan, "Quality improvement methodologies-PDCA cycle, RADAR matrix, DMAIC and DFSS," *J. of achievements in materials and manufacturing engineering*, vol. 43, no. 1, pp. 476-483, Nov. 2010.
- [19] M.E. Johnson, and S.I. Dubikovsky, "Incorporating Lean Six Sigma into an Aviation Technology Program," in *Proc. of SEFI 2008 Annual Conf.*, West Lafayette, IN, USA, 2008.
- [20] D. Gošnik, I. Beker, and K. Kavčič, "Lean six sigma in Slovenian and Serbian manufacturing companies," *Int. J. of Industrial Engineering and Management*, vol. 5, no. 3, pp. 123-130, Oct. 2014. [Online]. Available: www.iim.ftn.uns.ac.rs/fjiem_journal.php
- [21] Viewer Point, Background and Meaning of Six Sigma Part 1. (Nov. 26, 2018). Accessed: Jun. 13, 2020. [Online Video]. Available: <https://www.youtube.com/watch?v=j2MNIYUdzOk>
- [22] T. Pyzdek, *The Six Sigma Handbook*. New York, NY, USA: McGraw - Hill, 2001.
- [23] S. Gomes, and M. João, "Improvement of Segment Business using DMAIC Methodology: A Case Study," *Int. J. of Performability Eng.*, vol. 6, no. 6, pp. 561-576, Nov. 2010.
- [24] S.C. Ellis, T. J. Goldsby, A. M. Bailey, and J.-Y. Oh, "Teaching Lean Six Sigma within a Supply Chain Context: The Airplane Supply Chain Simulation," *Decision Sciences J. of Innovative Education*, vol. 12, no.4, pp.287-319, Oct. 2014, doi:10.1111/dsji.12043.
- [25] N. Kaufmann, *Lean Six Sigma Nuggets: A Fully Commented Project Documentation*, Singapore: Partridge Publishing, 2018.
- [26] A. Kumar, and N. Sharma, "Six Sigma DMAIC methodology: a powerful tool for improving business operations," *Advanced Materials Research*, vol. 488-489, pp. 1147-1150, Mar. 2012, doi: 10.4028/www.scientific.net/AMR.488-489.1147.
- [27] T. Pyzdek, *The Six Sigma Handbook*. New York, NY, USA: McGraw - Hill, 2001.
- [28] S.C. Ellis, T. J. Goldsby, A. M. Bailey, and J.-Y. Oh, "Teaching Lean Six Sigma within a Supply Chain Context: The Airplane Supply Chain Simulation," *Decision Sciences J. of Innovative Education*, vol. 12, no.4, pp.287-319, Oct. 2014, doi:10.1111/dsji.12043.
- [29] B.J. Singh and D. Khanduja, "Perspectives of control phase to manage Six Sigma implements: an empirical study," *Int. J. of Business Excellence*, vol. 7, no.1, pp. 88-111, Dec. 2013, doi: 10.1504/IJBEX.2014.057860.
- [30] E. Nelson, "Using Six Sigma and Lean in the Library," *J. College & Undergraduate Libraries*, vol. 22, no. 3-4, pp. 312-324, Dec. 2015, doi: 10.1080/10691316.2015.1070701.
- [31] J. H. Sanders, and T. Karr, "Improving ED specimen TAT using Lean Six Sigma," *Int. J. Health Care Quality Assurance*, vol. 28, no.5, pp. 428 - 440, Jun. 2015, doi: 10.1108/IJHCQA-10-2013-0117
- [32] K. Knop, (2016). "Using a QFD method and CTQ tree to identify the areas needing improvement in the product-farm truck trailer," *Zeszyty Naukowe. Organizacja i Zarządzanie/Politechnika Śląska*, vol. 87, pp. 219-236, 2016. [Online]. Available: <http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-4c0859d5-2d9c-4103-b3bd-be59333b3e1f>
- [33] A. Prashar, "Adoption of Six Sigma DMAIC to reduce cost of poor quality," *Int. J. of Productivity and Performance Management*, vol. 63, no. 1, pp. 103-126, Jan. 2014, doi: 10.1108/IJPPM-01-2013-0018.
- [34] M.S. Mia, M.D. Nur-E-Alam, and M.K. Uddin, "Court shoe production line: Improvement of process cycle efficiency by using lean tools," *Leather & footwear J.*, vol. 17, no. 3, pp. 135-146, Jun. 2017, doi: 10.24264/lfj.17.3.3.
- [35] L. Socconini, *Lean Six Sigma Yellow Belt*. Barcelona, España: Marge Books, 2014.
- [36] A.J. Dal Forno, F. A. Pereira, F. A. Forcellini and L.M. Kipper, "Value Stream Mapping: a study about the problems and challenges found in the literature from the past 15 years about application of Lean tools," *The Int. J. Advanced Manuf. Technol.*, vol. 72, no. 5-8, pp. 779-790, Feb. 2014, doi: 10.1007/s00170-014-5712-z.
- [37] A. Shaw, *Time Study Manual of the Erie Works of the General Electric Co.* Erie, PA, USA: 1978.
- [38] G. Koenigsaecker, "Measurement can be easy," in *Leading the lean enterprise transformation*. Boca Raton, Florida, USA: CRC Press, 2012, ch. 3, pp. 18-25.
- [39] E.M. Keim, "Rethinking the Basics: Takt Time and Work load Balancing," *The J. for Quality and Participation*, vol. 41, no.4, pp. 30-32, Jan. 2019, [Online]. Available: <https://search.proquest.com/docview/2208627208?pq-origsite=gscholar&fromopenview=true>
- [40] A.J. Dal Forno, F. A. Pereira, F. A. Forcellini and L.M. Kipper, "Value Stream Mapping: a study about the problems and challenges found in the literature from the past 15 years about application of Lean tools," *The Int. J. Advanced Manuf. Technol.*, vol. 72, no. 5-8, pp. 779-790, Feb. 2014, doi: 10.1007/s00170-014-5712-z.
- [41] S.O.N.G. Hai-rong, "Comments on "A New Product Growth Model for Consumer Durables," *J. Shijiazhuang University of Economics*, vol. 6, pp. 7, 2004. [Online]. Available: http://en.cnki.com.cn/Article_en/CJFDTotat-HB DX200606007.htm
- [42] R. Bakerjian, *Tool and Manufacturing Engineers Handbook: Volume 6, Design for Manufacturability*. Dearborn, Michigan, USA: Society of Manufacturing Engineers, 1992.
- [43] V.D. Radojicic and G.Z. Markovic, "New Technology Forecasting Using the Bass Model," in *9th International Conference on Telecommunication in Modern Satellite, Cable, and Broadcasting Services*, Nis, Serbia, 2009, pp. 215-227, doi: 10.1109/TELSKS.2009.5339534.
- [44] C. Valdivieso, O. Valdivieso, and R. Valdivieso, "Determinación del tamaño muestral mediante el uso de

- árboles de decisión,” *Investigación y Desarrollo*, no. 311, pp. 148-176, Jan. 2011. [Online]. Available: <http://www.upb.edu/RePEc/iad/wpaper/0311.pdf>
- [45] C. L. Leaphart, et al. “Formal quality improvement curriculum and DMAIC method results in interdisciplinary collaboration and process improvement in renal transplant patients,” *J. Surgical Research*, vol. 177, no.1, pp. 7-13, Sept. 2012, doi: 10.1016/j.jss.2012.03.017.
- [46] B.R. Jadhav, S.J. Jadhav, “Investigation and analysis of cold shut casting defect and defect reduction by using 7 quality control tools,” *Int. J. Adv. Eng. Res. Stud.*, vol. 2, pp. 28-30, Jul./Sept. 2013. [Online]. Available: <http://www.technicaljournalonline.com/ijaers/VOL%20II/IJAERS%20VOL%20II%20ISSUE%20IV%20JULY%20SEPTEMBER%202013/328.pdf>
- [47] I.C. Braga, F. da Silva Brandão, F.R.C. Ribeiro, and A.G. Diógenes, “Application of GUT Matrix in the assessment of pathological manifestations in heritage constructions,” *Revista ALCONPAT*, vol. 9, no. 3, pp. 320-335, Aug. 2019, doi: 10.21041/ra.v9i3.400
- [48] J. Cottyn, H. Van Landeghem, K. Stockman and S. Deramelaere, “A method to align a manufacturing execution system with Lean objectives,” *Int. J. Production Research*, vol. 49, no. 14, pp. 4397-4413, Mar. 2011, doi: 10.1080/00207543.2010.548409.
- [49] R. Charron, H. Wiggin, F. Voehl, and H.J. Harrington, “Lean concepts, tools and methods,” in *The lean management systems handbook*. Boca Ratón, FL, USA: CRC Press, 2014, ch. 9, pp. 254-276.
- [50] S.M. Ho, “The 5S auditing,” *Managerial Auditing J.*, vol. 14, no. 6, pp. 294-302, 1999
- [51] A. Lešková, “Principles of lean production to designing manual assembly workstations,” *Annals of the Faculty of Engineering Hunedoara-Int. J. Engineering*, vol. 11, no. 2, pp.31-36, 2013. [Online]. Available: <http://annals.fih.upt.ro/pdf-full/2013/ANNALS-2013-2-03.pdf>
- [52] G.F. Barbosa, J. Carvalho and E.V.G. Filho, “A proper framework for design of aircraft production system based on lean manufacturing principles focusing to automated processes,” *Int. J. Adv. Manuf. Technol.*, vol. 72, no. 9-12, pp. 1257-1273, Jun. 2014, doi:10.1007/s00170-014-5729-3
- [53] W.P. Helgeson, and D.P. Birnie, “Assembly Line Balancing Using the Ranked Positional Weight Technique,” *J. of Industrial Eng.*, vol. 12, no. 6, pp. 394-398, 1961.
- [54] J. Ocampo, and A. Pavón, “Integrando la metodología DMAIC de Seis Sigma con la Simulación de Eventos Discretos en Flexsim,” presented at the 10th LACCEI Latin American and Caribbean Conference for Engineering and Technology, Panama City, Panama, Jul. 23-27, 2012, Paper 147.
- [55] S.C. Ellis, T. J. Goldsby, A. M. Bailey, and J.-Y. Oh, “Teaching Lean Six Sigma within a Supply Chain Context: The Airplane Supply Chain Simulation,” *Decision Sciences J. of Innovative Education*, vol. 12, no.4, pp.287-319, Oct. 2014, doi:10.1111/dsj.12043.
- [56] C.A.C. Araujo, “Desenvolvimento e Aplicação de um Método para Implementação de Sistemas de Produção Enxuta utilizado os Processos de Raciocínio da Teoria das Restrições e o Mapeamento do Fluxo de Valor,” Ph.D. dissertation, Dept. Production Eng., Univ. São Paulo, São Carlos, Brazil, 2004.
- [57] J.P. Womack, D.T. Jones, and D. Roos, *The Machine that Changed the World*. New York, NY, USA: Rawson, 1990.
- [58] R. Castillo, J. Vásquez, P. Ramírez and M. Carrillo, “Consideraciones para el rediseño de la línea de ensamble de vehículos aéreos no tripulados desarrollados por la Fuerza Aérea Ecuatoriana,” *INGE CUC*, vol. 12, no. 1, pp. 51-64, Jan./Jun. 2016, doi: 10.17981/ingecuc.12.1.2016.05.
- [56] A. J. Thomas, M. Francis, R. Fisher and P. Byard, “Implementing Lean Six Sigma to overcome the production challenges in an aerospace company,” *Production Planning & Control*, vol. 27, no. 7-8, pp. 591-603, Mar. 2016, doi: 10.1080/09537287.2016.1165300.
- [57] P. Garre, N. Bharadwaj, P. S. Shashank, M. Harish, and M. S. Dheeraj, “Applying Lean in Aerospace Manufacturing,” in *Materials Today: Proc. J.*, vol. 4, no. 8, 2017, pp. 8439-8446, doi:10.1016/j.matpr.2017.07.189.