Toyota Production System in Aircraft Industry – A Case Study

Setyo Utomo Soekarsono and Hardianto Iridiastadi
Master program in Industrial Engineering and Management
Bandung Institute of Technology
Setyo.soekarsono@gmail.com, hiridias@vt.edu

Yustiono Dwi Arianto
PT Dirgantara Indonesia
Bandung
yustiono@indonesian-aerospace.com

Abstract

Three years after the lean manufacturing plan was first put forward by Womack and Jones in 1990 in his book The Machine That Changed the World, US Airforce and MIT initiated the establishment of the Lean Aerospace Initiative (LAI) to study the application of lean manufacturing in the aircraft industry. PTX as an aircraft manufacturing industry has been applying this lean manufacturing concept since 2013 which operation was performed gradually into 7 stages. This paper will explain how the process of applying lean in PTX has been going, and what results it has obtained. A Comparison with the literature on the application of lean in the HMLV industry in general, and the aerospace industry in particular was done to be able to provide a more complete understanding of the process of lean implementation in PTX. In accordance with the literature, PTX had also to modify some lean tools before they put the concept into application, in addition to some tools that can be utilized directly. In overall, the application of lean manufacturing concept in PTX has managed to increase production effectiveness by 70%, reduced production lead time and defect to 60% and 40% respectively, and reduced inventory by 60%.

Keywords
Lean Manufacturing, Lean Implementation, Aircraft Manufacture, HMLV, LAI.

1. Introduction

Since its introduction by Womack in 1990, lean manufacturing has been a popular preference to the manufacturing industry to improve the efficiency and effectiveness of manufacturing process. Not only to serve manufacturing process for discrete industries (such as automotive, home appliances etc.), but also for process industries (garment, pharmaceutical, consumer goods), and has been adopted even in the service industry (Amrani and Ducq 2020; Tomašević et al. 2020). The motivations to apply lean manufacturing in the industry are varied, among others it is because of the business competition that constantly requires a competitive advantage as to lowering costs, increasing quality and shortening delivery time (Tomašević et al. 2020). In aerospace industry, the study of lean application was initiated by MIT in 1993 on the initiative of U.S. Airforce by forming the Lean Aerospace Initiative (LAI) to anticipate the problem of declining state budgets for the procurement of aerospace equipment, and to avoid stagnation of the aviation industry due to the emergence of competitors from Europe (Murman et al. 2002). LAI was a collaboration among industries, government, academics, and other aerospace stakeholders, which objectives of the study included on how to apply lean to increase efficiency, and to get higher quality products with more affordable costs. (Murman et al. 2002). The results obtained were the particular stages of lean application in the aerospace industry at the production level and also at the enterprise level (Crabill et al. 2000; Murman et al. 2002). For industry practitioners, the big question was whether the methods offered were suitable to be applied in the company, where geography, demography, and culture were different, what steps to take to implement lean, and what lean tools that would best to be applied to achieve the desired objectives, and moreover the question was how to measure the success of the lean application, what would be the measure for the key success as well as the challenges faced when applying lean.

1.1 Objectives

The purpose of this paper is to observe and study the application of lean manufacturing in the production floor of one of the aircraft manufacturing companies in Asia. The findings obtained will then be compared to the concepts and theories in literature to have the answer to the research questions and give a better understanding of the application of lean, and how the concept may also be successfully applied in similar industries.

2 Literature Review

2.1 HMLV vs LMHV

Based on the capacity in volumes, and the type of products it makes, the automotive industry is categorized as a Low-mix High-volume (LMHV) type of industry, while the aircraft industry is a High-mix Low-volume (HMLV) industry (Irani 2020). To further clarify the differences between aircraft product from car products, table 1 shows as follow (Wildemann and Hojak 2016);

Table 1. Product and production differences between aircraft and automobile (adopted from Wildeman and Hojak (2016))

		Aircraft (A320)	Automobile (Audi A3)
Product	Power (HP)	>66.000	>100
	Maximum speed in km/h	- 900	- 200
	Size in m (length * width * height)	- 40 * 34 *12	5 * 2 *1.5
	Model portfolio (without derivative)	- 4	- 12
	Possible combinations for customer equipment levels	- 10^{34}	- 10^{35}
	Development time until SOP in years	- 7	- 4.5
	Customers worldwide	- 400	- 100.000
	Number of components (pieces)	- 3.000.000	- 18.000
	Selling price in EUR	- 9.000.000	- 27.500
	Operational life in years	- 40	- 9
	Fuel consumption per 100 km and person in liters	- 3	- 5
Production	Empty weight in tons	- 60	- 1.6
	Production capacity per year	- 260 (Hamburg)	- 130.000 (Ingolstadt)
	Shifts per day	3	3
	Assembly time in hrs. (only final assembly line without aircraft painting)	- 720	- 21
	Depth of added value (equity ratio) in %	- 30	- 27
	Number of workers per shift	- 500	- 500
	Production type	Mini-series production	Mass production
	Suppliers	- 2.000	- 110
	Logistical expenditure per production in percent of the selling price	- 5	- 1.5
	Staking points / weld points	- 1.000.000	- 5.100

The comparison between HMLV and LMHV can be seen in the number of products available in the market, number of customers, production capacity, and the number of units of components that create the product. Aircraft are made based on order only (builds to order), and 80% of the total cost is in the design phase (Crute et al. 2003). LMHV industry implements industrial assembly line process, while HMLV can apply a combination of manual cells, flexible manufacturing cells, and job shop (Irani 2020). Overall the environment of HMLV differs from LMHV (Irani 2020; Tomašević et al. 2020). The main differences of HMLV to LMHV are in the facility layout and production scheduling, in which HMLV uses functional layouts and ERP (Irani 2020)

2.2. Lean application on the Aircraft manufacturing industry.

The basic principle in implementing the lean manufacturing concepts is to set values, develop map value streams, set production flows, utilize pull systems, and last but not least is to always try to reach for the best (Womack et al. 1990). The implementation of lean manufacturing undergoes 3 stages, namely the application of lean culture, developing lean skills, and a continuous improvement (Wan and Chen 2009)

2.2.1 Aircraft industry as HMLV industry

Due to the different characteristics between HMLV and LMHV, the lean application offered by Womack et al., will have to be modified according to the characteristics of the HMLV industry (Irani 2020). According to Irani (2020), the application of lean begins with determining the product family, followed by determining the value network mapping, namely VSM conducted for the product family, and then identifying seven types of waste from VNM, identify and eliminate bottlenecks, evaluate performance and optimization of VNM, then repeat the process

from beginning for other product families. For a HMLV industry, Lane (2007) explained that prior to applying lean in factory floor, the company must possess a good quality level, and to apply lean also in the office.

2.2.2 Lean Aerospace Initiatives

LAI developed a roadmap for lean implementation for production processes in the aerospace industry. The roadmap consists of 7 stages. Each stage is to be implemented with some adjustment to the actual conditions of the ongoing production process, see figure 1 (Crabill et al. 2000).

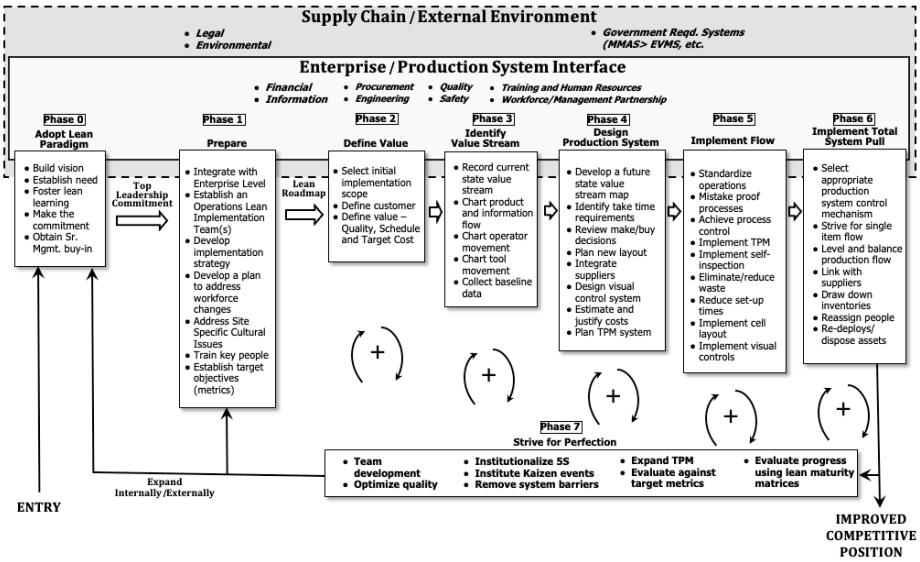

Figure 1. Production operations transition-to-lean Roadmap (Crabill et al., 2000)

2.3. Lean tools used in the aircraft industry.

The application of lean tools in the aircraft industry must take into consideration the characteristics of the industry. For the aircraft industry, Amrani and Ducq (Amrani and Ducq 2020) mentioned that there were 8 lean tools that could be used in accordance with the characteristics of the aircraft industry. These 8 lean tools were:

1. U cells
2. One-piece flow
3. Visual Management
4. Standard work instructions
5. Takt Time
6. Poka-yoke
7. SMED
8. Multi-skills

The eight tools bears the characteristics of the aircraft industry, which shows high demands, having diversification of demands, product complexity, high safety and quality requirements, and a complex chain of supply (Amrani and Ducq 2020).

Irani (2020) mentions that not all of the tools in lean are suitable for use in job shops. Some tools require modifications before use for application. Table 2 shows which lean tools that can be applied and which ones that cannot (must be checked first before used) based on Irani (2020).

Table 2. Lean tools to use and to avoid in Job Shop. Adopted from Irani (2020)

Lean Tools to Use	Lean Tools to Avoid
• Employee engagement	• FIFO sequencing of orders
• Workplace design with 5S	• Manual scheduling with whiteboards
• Total productive maintenance (TPM)	• Mixed model production with Takt Time
• Error-proofing (Poka-Yoke)	• One-piece flow cells
• Quality at source	• Pacemaker scheduling
• Visual workplace	• Inventory supermarkets
• Product and process standardization	• Work order release based on pitch
• Right-sized flexible machines	• Pencil-and-paper problem-solving
• Setup reduction (SMED)	• Product-specific Kanbans
• Standard work	• Production based on level loading
• Continuous problem-solving	• Pull-based production scheduling
• Strategic planning	• Right-sized inflexible machines
• Top-down leadership	• Value Stream Mapping
• Gemba walks by managers	• Assembly line balancing

Based on Lean Aerospace Initiatives, the lean tools that can be used in the aerospace industry are (Crabill et al. 2000):

1. Balanced Production Flow
2. Cycle Time
3. 5S
4. Flow Process-oriented flow, flow Kaizen
5. Just in Time (JIT)
6. Kaizen
7. Kaizen Event
8. Kanban
9. Production Flow Level
10. Pull
11. Takt Time
12. TPM
13. Value
14. Value Stream Map
15. Visual Controls
16. Waste

Which lean tools to be most suitable for each company will depend on the conditions of the company.

2.4. Lean maturity in the aircraft industry.

Lean implementation in one organization has not always been successful (Bozdogan et al. 2000; Crute et al. 2003). The factors that determine the success of lean implementation includes: change strategies, effects of company culture, product focus, senior management commitment and consistency of focus, and time and space for performance improvement (Crute et al. 2003). To be successful, the most difficult change to implement is the cultural change (Hallam and Keating 2014). Lean transformation requires a change in behavior, not only in individuals', but also in companies' (Bozdogan et al. 2000; Hallam and Keating 2014; Liker 2004). To know the success of lean application, it is necessary to measure what has been achieved by using lean assessment tools.

Lean assessment tools are generally used to meet two needs, the first is to know the extent to which lean application has been achieved, and the second is what impact it makes. Ideally, lean assessment tools used should be in accordance with the nature of the organization itself, and the industry would choose the tools that have been proven to be used successfully by similar industry (Oleghe and Salonitis 2018). There are several methods developed by academics, lean groups, and practitioners, among others it is AME Lean Sensei and LESAT (Oleghe and Salonitis 2018). AME Lean Sensei (ALS) was created by the American-based Manufacturing Excellence Association that can be used at any level in the industries (AME 2021) while LESAT (Lean Enterprise Self-Assessment Tool) is an assessment tool developed by LAI to measure the maturity of lean application at the enterprise level (Hallam and Keating 2014). Both ALS and LESAT are self-assessments tools using qualitative data obtained from answering the questions given.

3. Methods

This research uses a case study method. Data used in the case study were obtained from structured interviews via video conference, company documents, pictures, including questions and answers via online communication. Due to the occurring pandemic, a visit to factory facilities could not be performed. The questions made for the interview were based on literatures that have been studied previously. The interview results were validated with respect to company documents obtained as well as other supporting data (photos and Q%A) or vice versa. The final result of the data analysis is then compared with the theory in literature to draw a conclusion.

Respondent is the person responsible for the implementation of lean implementation in the factory. Involved in the process from the beginning of lean implementation in the industry, serving as a change agent until now. Unless the source of the information is mentioned, then all information comes from the results of the interview.

4. Lean Implementation in Production Division at PT X

PTX is an aircraft manufacturer located in Southeast Asia. In addition to producing its designed-made aircraft, PT X is referred to as an OEM (Original Equipment Manufacturer), its production directorate also makes parts for other OEMs as a tier-three supplier. To note that Tier-two suppliers are suppliers for assembly or equipment products, while tier-one is the system integrators (Richter & Walther 2017).

4.1 Introduction

Aircraft parts design and their production process, is a unity that cannot be separated because they both concern with the airworthiness of the aircraft structure (DGCA 2014). Should there be a process that can not be fulfilled by the shop floor, and need to be replaced, then the decision must be approved first by the designer and the authority. If the manufacture of parts is to be sub-contracted to the other party, then the quality system of the supplier, the other party, must comply with the quality system of the OEM (DGCA 2015).

At the OEM, what machines to be needed and how the process will run for making the parts are determined in line with the aircraft design process. Any supplier of tier 3 must have machines and processes in accordance with the design provided by OEM. If the existing facilities and processes are not sufficient, then a modification must be taken, otherwise new investment will be required. The ability to adapt to variations of different customer requirements, in term of manufacturing facilities and processes, will be a competitive advantage for aircraft component manufacturers.

4.2 Motivation to apply lean.

Customer demand, aggressive competitors and environmental changes are the reasons for the continuous improvement goals of PTX. In addition to being an OEM, PTX strives to become a tier 3 and 2 suppliers for the larger aircraft industry. To be able to compete, PTX has to have a competitive advantage. It is for that reason that PTX applied lean.

4.3 Lean implementation roadmap

The first step PTX did in order to apply lean was to get a partner who could perform as a lean expert. Once the partner was obtained, PTX then created a team as the first lean change agent to study lean and its implementation at the partner's location, and established the lean implementation program at the manufacturing shop floor.

4.3.1 Getting a lean partner

Obtaining a partner who had implemented lean was the way PTX had chosen. The Partner, who had successfully implemented the lean, was selected from partners who had business portfolios similar to PTX, all in terms of product type, business size, machinery, and organizational structure. After obtaining a partner, 15 people from 6 divisions in the Directorate of Production were sent to the partner’s facilities to study, learn and did workshops on lean manufacturing and applications. The 15 people were the first lean change agent of PTX.

The team of 15 people accomplished to develop a complete specified lean program including the tools, processes and documents as the result of what they have learned from the training. To ensure that the implementation of lean would be carried out as planned, 4 lean departments were formed at 4 divisions: Detail Part Division, Sub-assembly Division, Final Assembly Division, and Manufacturing Engineering Division. To make certain that the implementation of lean went according as planned, a steering committee was formed to monitor and control the implementation of the plan.

4.3.2 Lean internal training

PTX believed that the success of lean would depend on full participation of all employees and management altogether. PTX then formed a training center, say a “Lean Academy”, which was dedicated for the implementation of this lean program. There were two main programs provided in the Lean Academy: The Initial training, and the Recurrency training. The Initial training introduced the theory and discussion on the introduction of lean, as well as providing an exposure to the implementation of lean practices by using a model of aircraft assembly process called Lean Model Factory. The Initial lean training generally took 2 weeks. All the 1800 employees and management officers in the Production Directorate participated in the Initial training. The Recurrency training was created to update, upgrade, and refresh the lean theory and practice of lean, which course of study and syllabus were prepared with regards to the maturity level of lean application in the production floor.

4.3.3 Lean manufacturing implementation

In putting into practice lean on the production floor, PTX developed stages of implementation called Lean Maturity Model, as shown in figure 2. The application of lean on Maturity Model was divided into two sides, one for team formation, and another for implementation of lean tools. The stage of team formation, and the stage of application of lean tools were arranged one to the other based on phases. The duration of each phase in each side could be different. The application of lean tools would be introduced after men power were fully capable to utilize and run related tools

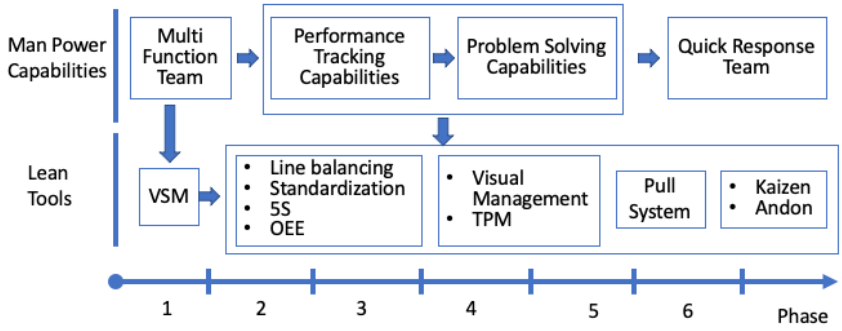

Figure 2. PTX Maturity Model
Note: Except VSM, the implementation stage is not correlated with the phases

Upon completion of the training, the first program conducted by each section was to appoint a Multi-Function Team (MFT) whose main task was to make Value Stream Mapping (VSM) with purpose to identify waste and to plan future state. The future state of VSM is then broken down into several Target Improvement Plans (TIP) which will become KPIs of each section. VSM and TIP are the fundamental points for the next steps to determine the application of tools, and to form a team. TIP contains decisions of which lean tools would be needed to improve performance, set the time as when to implement the tools as well as to make ready the supporting tools needed. The supporting tools are the tools used to measure how much deviation is from performance target, and to correct them when irregularities occur. The lean tools used by PTX after VSM/TPI implementation are shown in figure2.

In order to implement lean tools properly, PTX scheduled daily routine meetings @ 15 minutes at all levels as part of a way to monitor, to know deviations when occur, and to find problem solving solutions. Level 1 meeting is a meeting among machine operators led by the lead team. Level 2 meetings are among team leads led by supervisors, level 3 meetings are meetings among supervisors led by managers, and level 4 meetings are meetings among managers led by the head of the division. Level 5 meetings are among division heads and directors, conducted once a week. Level 1 to level 4 meetings are held on the production floor. The meetings right at the production floor was meant also to bring the management to go down to production floor to see directly the actual problems. The subjects discussed in regular meetings are matters that related to the quality, cost, and delivery time of the product, with safety and personnel factors, so referred to as QCD-SP meetings, and the material discussed is referred to as QCD-SP panel. These meetings are very important, not only to be aware and be updated on the status of the products, these meetings are also a way to develop and maintain lean culture among people involved. Any problem that cannot be solved in QCD-SP meeting will be handled by MFT team.

MFT is a team whose main task is to solve problems arising in the field that can not be solved in QCD-SP meeting. MFT consists of personnel representing all functions at the production floor. The combination of personnel from several different functions, is also intended to establish good communication among parties, to eliminate the silos that may previously existed. If the problem cannot be solved instantly, then MFT would bring the problem to a larger forum called Practical Problem-Solving Meeting (PPSM), which contains, in addition to MFT members, also representatives from other parts of PTX needed to help solve the problem. Decisions and the process of the problem solving are all well recorded and administrated according to requisite procedures. These records are the necessity for the product's quality and certification processes. In solving the problem, the “5W” technique becomes one of the standard procedures. The implementation of QCD-SP meetings every day is expected also to make MFT and PPSM teams become more trained and more responsive in solving problems that arise at production floor. Having MFT and PPSM who are well trained, responsive and possess the culture and lean attitude is the main goal of the implementation of lean in terms of human resources. This team is referred to as Quick Response Team (QRT).

4.4 Lean tools used by PTX

According to PTX, lean manufacturing is defined as a production system that aims to conduct activities to meet customer demand, in accordance with the agreed quality, cost, and delivery time, and focus on elimination of all things that do not provide added value. The application of lean tools is adjusted to the maturity of the implementation team by following the stages that have been determined in the maturity model. Some lean tools needed to maintain performance, measure achievement and find root cause problems, were modified before use (See table 3).

Table 3. Grouping of lean tools at PTX

Lean Grouping	Lean Tools	Modified Lean Tools
Improvement strategy	• 5S • Kaizen • Line balancing • OEE • Pull system • Standarization • Takt time • TPM • VSM	• E-Kanban • Multi Function Team • Quality Management Board • Quick Response Team • Target Improvement Plan • Vendor's supply: Tooling, Part supply,Aux Material, Sealant, Fastener
Maintain the improvement		• Process Confirmation • Improvement Tracking System
Measure the deviation		• KPI • QCD - SP Meetings • QCD – SP Panels • Tracking OEE • Performance Tracker
Root cause of deviation	• Andon	• Practical problem solving

A brief explanation of some of the lean tools used are as follows:

- 5S is an activity conducted as soon as the training is completed by following the operational instructions prepared by lean department. Along with the 5S, OEE was also implemented.
- VSM is the first lean activity conducted to determine the next step of the implementation of lean (TPI). VSM is made for product family based on process similarities or technology groups. Output of VSM submitted is a future state which contains takt time and line balancing, as well as the proposal for layout of the machining process. Future state is made with regards to customer needs previously determined by management.
- Line balancing and takt time are created when composing VSM. Line balancing and takt time are made in various arrangements according to product variations that have been made before. The purpose is to be able to quickly anticipate when any change in customer demand arises.
- Standardization: In the aircraft manufacturing industry, each part made must have a specific working process. This is part of the regulation. Thus, standardization is already an inseparable process.
- TPM is a tool used to improve OEE. OEE can be implemented at the beginning of the phase, but TPM can only be implemented after the team is proficient in detecting, measuring, and correcting deviations that occur, and has an intensive study on how TPM works and having keen knowledge on the maintenance of the equipment itself.
- Pull system. PTX applies pull system for the needs of consumable materials (cutting tools, sealant, fastener, and other standard parts).
- Kaizen is the top target that PTX wants to achieve. To make kaizen as part of the company's culture, continuous efforts were carried out through, among others, regular meetings (QCD-SP meetings), discussions, posters, refresh training, and on every occasion delivered by change agents or team management.

Short explanation on some modified lean tools

- Performance tracker is a visual management tool used to view production status. Placed in the production floor area so that all parties can see the current status. The display would be updated at every shift change. Performance trackers began to be implemented after employees had become accustomed to QCD-SP meetings.
- QCD-SP meeting is performed every day at the production floor and attended by manager and head of division. It is as a gemba genchi genbutsu in TPS
- Vendor's supply is the way how PTX reduce inventory in consumables materials. A special space at the production floor is provided for vendors of the consumables to place their products, equipped with e-Kanban for their inventory system.

- Target improvement plan and KPI are the tools like a future state of value stream mapping
- Multi-function team, quick response team, and practical problem solving are tools used as in-station quality controls and solved root cause of problems (5Why's)

In overall, PTX uses all the tools to use in job shops including VSM (see table 2)

4.5 Lean maturity

PTX measures the accomplishment of its lean implementation with regards to the plan it set previously, as part of the monitoring and controlling process. The lean assessment tools provided in literatures or made by any other industries, are unable to meet its particular needs. To measure the lean implementation, PTX utilizes a quality checklist forms. Every lean tool applied would have their particular quality checklist. Quality check list contains targets that must be met, and are distinguished between mandatory action and other key points. There are only 5 mandatory actions and no more than 15 other key points with 3 level of completion, Green, Yellow, and Red. Red if at least one mandatory action is not finished yet. Yellow if less than 50% key points are not fulfilled. Green if more than 50% key points are finished. During internal discussions, lean maturity assessments are conducted by calculating the planned completion of the program, compared to the overall target.

4.6 Results achieved

PTX is still in the process of completing the seven phases planned. Until this paper was made, the overall application of lean manufacturing concept in PTX has managed to increase production effectiveness by 70%, reduced production lead time and defect by 60% and 40% respectively, and reduced inventory by up to 60%. In addition to the performance improvement, lean implementation at PTX have gained increasing trust from the global aviation industry. PTX has received orders for making parts from one of the largest OEMs in the world. Although currently it is still serving as a tier 3 supplier, but it is expected that PTX will become a tier 2 supplier.

Looking through all the experience of implementing lean, the issues of uplifting human resources as well as the consistency to implement lean culture appear to be the most in need for special attention from all parties during the lean implementation. Therefore, the commitment of top management must always be maintained.

5. Results and Discussion

This is the discussion on the interview results that was conducted by referring to the theory discussed in chapter 2.

5.1 Lean implementation

PTX applied lean for two things, one was for establishing lean operation process in the industry, and two was to have and make use a QRT that possess a lean culture and attitude. The lean operation process is achieved by applying lean tools, and the QRT is obtained by forming a well-trained MFT and PPMBS teams.

5.1.1. Lean motivation

PTX's motivation in implementing lean was in accordance with what is described in the literature study made by Amrani and Ducq (2020), which firstly was to increase the competitive advantage in order to get contracts from large OEMs, and secondly was to utilize lean production system to be able to produce products with better quality, lower cost, and shorter delivery time, for its internal OEM parts and for other products as a tier 3 supplier.

5.1.2 Lean partners

PTX's decision to find lean partner saves a lot of time and efforts in defining what platform and tools to be used, acquires knowledge on how to make the stages and more. In fact it is not easy to apply lean, the literature study showed that 90% of companies had applied lean in such an improper way, and only about 2% gained the results as expected (Amrani and Ducq 2020). A deep understanding of lean is required, altogether with a clear understanding of the overall operation of the company before implementing lean (Amrani and Ducq 2020). Therefore, the existence of lean application method provided by LAI for specific aerospace industry is very helpful, as a guidance for steps and tools to be implemented.

5.1.3 Lean training

The establishment of PTX's Lean Academy shows that PTX gave a great attention and intention to the readiness of its human resources, not only in understanding lean, but also in providing competency in lean-related skills. PTX also emphasizes that the application of lean tools is adjusted to the maturity of the human factors. This is in accordance with what is conveyed in the literature, that is for all party to firstly possess good understanding of the culture, skill and the application of lean (Amrani and Ducq 2020; Crabill et al. 2000; Wan and Chen 2009). It is

mentioned that one of the biggest challenges in implementing lean in PTX is managing human resources. This is in accordance with what Hallam and Keating (2014) said.

5.1.4 Lean team

Lean is about the beliefs and behaviors of all involved in the process (Bozdogan et al. 2000). PTX applies lean to get what was considered important by PTX in order to win the competition, as a respond to the customer request, that is to have a cultured QRT. But in the literature studied, there was none mentioning that the goal of the application of lean is to get a team that responds quickly.

5.1.5 Lean roadmap

Learning what PTX has done, it can be concluded that the roadmap carried out was in accordance with what are suggested by the literatures (Crabill et al. 2000; Irani 2020; Wan and Chen 2009; Womack et al. 1990). In regards with LAI, instead of implementing the total pull system in phase 6, PTX target was to obtain a QRT and the integration of the suppliers of consumables into their operating system. Thus, LAI was used but the phase 6 was adjusted to fulfil with the particular goals of the company. PTX established a lean department specifically to create and maintain operational procedures and manage the execution of lean implementations. This is as mentioned in phase 1 of the LAI roadmap (see figure 1).

5.2 Lean tools

PTX uses lean tools and modified lean tools similar to what is used in Toyota Production System, and use all lean tools to use in job shop (see table 2). PTX uses VSM for one product family that has similarities in process or technology groups, not for one type of product only. This is in accordance with what Irani (2020) explained. In regards with the pull system, PTX uses this tool not as a part of the production process, but it uses as a tool to eliminate the waste in ordering process of consumable materials. Therefore, this study concluded that the lean tools proposed by Irani (2020) can be used, including the modified VSM.

Figure 3 shows the placement of lean tools used by PTX in TPS House. The italicized are the parts of TPS house (Liker 2004).

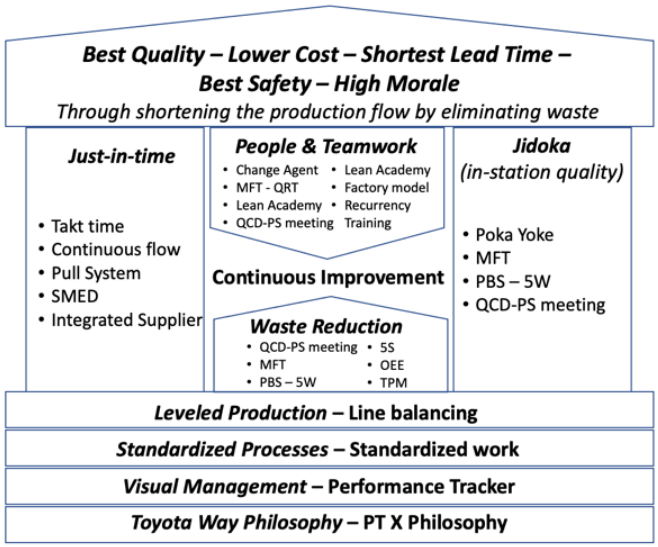

Figure 3. Lean tools use by PT X at TPS House (TPS is adopted from Liker 2004)

5.3 Lean maturity

The understanding of lean maturity for PTX is different from what is meant by lean maturity in literatures. Therefore, PTX does not use lean maturity tools available in the industry. The quality check list it used, was considered to be efficient enough to measure the progress of lean implementation. To know the impact of lean implementation, PTX uses a standard measurement used for the existing production processes. PTX is quite satisfied with the process of applying lean, because it has given significant results. Therefore, the steps, the processes, and the tools that were used by PTX can be a lesson for industry or academics who want to draw lessons from it.

6. Conclusions and Suggestions

PTX has succeeded in the application of lean, among others it is because PTX has managed to get the appropriate lean partner and puts the readiness of its human resources at first. The target to get a QRT team in addition to obtaining a lean production process is one thing that has not been discussed in literature used as a reference. The stages of application are in accordance with what is suggested by LAI by making modifications according to the needs, and by ensuring the ability of his human resources before implementing the lean tools. PTX uses all lean tools that can be used in the HMLV industry and use lean tools that require modification before use, in this case is VSM. To suit his needs, PTX uses quality check list form as a lean maturity assessment tool. It can be concluded that what PTX has performed in implementing lean was in accordance with what was stated in the literatures. To get a more thorough picture, it is recommended to continue the study of lean application in the assembly line process of aircraft.

References

AME, A. for M. E. 2021. *AME Excellence Award, AME LEAN SENSEI®*. https://www.ame.org/excellence-awards

Amrani, A., and Ducq, Y., Lean practices implementation in aerospace based on sector characteristics: methodology and case study, *Production Planning and Control*, vol. 31, no.16, pp. 1313–1335, 2020.

Bozdogan, K., Milauskas, R., Mize, J., Nightingale, D., Taneja, A., and Tonaszuck, D, *Transitioning to a Lean Enterprise: A Guide for Leaders, Volume 1: Executive Overview*, 2000.

Crabill, J., Harmon, E., Meadows, D., Milauskas, R., Miller, C., Nightingale, D., Schwartz, B., Shields, T., and Torrani, B, *Production Operations Level Transition-to-lean Roadmap* (Issue Version 1.0), 2000.

Crute, V., Ward, Y., Brown, S., and Graves, A, Implementing lean in aerospace - challenging the assumptions and understanding the challenges, *Technovation*, vol. 23, no. 12, pp. 917–928, 2003.

DGCA, I., *CASR 25 - Airworthiness Standards: Transport Catagory Airplanes* (Amdt 6). DGCA Indonesia, 2014.

DGCA, I., *CASR 21 - Certification Procedures for Product and Parts*, DGCA Indonesia, 2015.

Hallam, C. R. A., and Keating, J., Company self-assessment of lean enterprise maturity in the aerospace industry, *Journal of Enterprise Transformation*, vol. 4, no. 1, pp. 51–71, 2014.

Irani, S. A., *Job Shop Lean, An Industrial Engineering Approach to Implementing Lean in High-Mix Low-Volume Production Systems*, Routledge, Taylor & Francis, 2020.

Lane, G., *Made-to-Order Lean, Excelling in a High-mix, Low-volume Environment*, Taylor & Francis LLC, 2007.

Liker, J. K., *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*, McGraw-Hill, 2004.

Murman, E., Allen, T., Bozdogan, K., Cutcher-Gershenfeld, J., MacManus, H., and Nightingale, D., *Lean enterprize Value, Insights from MIT's Lean Aerospace Initiative*, Palgrave, Macmillan, 2002

Oleghe, O., & Salonitis, K., Leanness assessment tools and frameworks. In J. P. Davim (Ed.), *Progress in Lean Manufacturing*, Springer International Publishing, pp. 1–37, 2018.

Richter, K., and Walther, J., (Eds.), Supply chain integration challenges in commercial aerospace: a comprehensive perspective on the aviation value chain. *Springer International Publishing*, 2017.

Tomašević, I., Stojanović, D., Slović, D., and Simeunović, B., Jovanović, I., Lean in high-mix/low-volume industry: a systematic literature review, *Planning & Control*, 2020.

Wan, H. da, and Chen, F. F., Decision support for lean practitioners: a web-based adaptive assessment approach. *Computers in Industry*, vol. 60, no.4, pp. 277–283, 2009.

Wildemann, H., and Hojak, F., Main differences and commonalities between the aircraft and the automotive industry. In K. Richter & J. Walther (Eds.), *Supply Chain Integration Challenges in Commercial Aerospace: A Comprehensive Perspective on the Aviation Value Chain,* pp. 119–138, 2016.

Womack, J. P., Jones, D. T., and Roos, D., *The Machine That Changed The World*, Rawson Associates, 1990.

Biographies

Setyo Utomo Soekarsono obtained his bachelor's degree in Mechanical Engineering from Institut Teknologi Bandung (ITB), Indonesia, and earned his master's degrees in Aeronautical Engineering from Cranfield Institute of Technology, UK. He gained his Magister Management degree from Prasetiya Mulya Business School, Jakarta, Indonesia. He is currently a student of Magister Program of Industrial Technology and Management at Institut Teknologi Bandung, at the same time as a lecturer at Aviation Engineering Department at International Liaison University Indonesia (IULI). He had served as a Flight Test Engineer, and has interests in aviation safety and human factors, as well as to project management. He is a member of Indonesian Ergonomics Society.

Yustiono Dwi Arianto earned his bachelor's in Mechanical Engineering and master's degree in Industrial Engineering both from Institut Teknologi Bandung (ITB), Indonesia. He has been working for PT Dirgantara Indonesia as VP of Manufacturing Engineering, and has been in charged in most of technical coordinating programs for both external customers and internal new aircraft development programs. He has experiences in managing production and manufacturing aircraft parts, as well as developing a manufacturing engineering and production method, including manufacturing processes for new aircraft development.

Hardianto Iridiastadi earned his bachelor's degree in Industrial Engineering (IE) from Institut Teknologi Bandung (ITB), Indonesia. His master's and doctoral degree were obtained from Louisiana State University and Virginia Polytechnic Institute and State University, respectively. He is currently an Associate Professor within the Faculty of Industrial Technology at ITB. His research interests include occupational ergonomics, design of patient handling assistive device, and fatigue/workload in the transportation sector. He is a certified professional ergonomist (CPE), and was the President of the Indonesian Ergonomics Society. He has published a book entitled "Introduction to Ergonomics" (in Indonesian), a reference for undergraduate IE students.