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# Lean practices implementation in aerospace based on sector characteristics: methodology and case study

Aicha Amrani and Yves Ducq

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Lean production (LP) consists of very useful techniques; however, its implementation can significantly vary from one sector to another or from one practitioner to another. Although several lean experiences exist in aerospace, no specific method has been developed to adapt lean tools to the characteristics of the aerospace sector. This study uses a case based approach to analyse the implementation of lean practices in a company operating in the aerospace industry. The overall characteristics that motivate current aerospace companies to pursue lean conversions are identified – market demand, product diversification, product complexity, safety focus and agile supply chain. This paper aims at building a methodology including identified steps and their analysis to sustain the lean implementation. It is based on the analysis of the industrial context, which is linked to different practices and tools issued from LP. Apart from the aerospace sector, the methodology can also be adjusted and adopted by other sectors. Lean practices, such as the cellular layout, the one-piece flow, visual management, takt time, standardization, multiskills, poka yoke and SMED, were used in the proposed model and yielded significant gains. The defect rate dropped by 66%, the cycle time was reduced with 43% of savings, waste elimination was achieved, and the work-in-progress (WIP) inventory decreased. Furthermore, the illustrated impact of the lean manufacturing implementation on extending lean thinking to the logistics department presented 50% savings in transportation-truck costs. It serves as a proof of concept for the expansion of lean thinking.

**KEYWORDS** Lean production; lean practices; lean transportation; lean implementation; case study; aerospace

## 1. Introduction

Lean practices have proven to be significantly beneficial in various industrial sectors, such as food industry (Dora et al. 2013), steel milling (Abdulmalek and Rajgopal 2007), automotive industry (Cagliano, Caniato, and Spina 2004; Rahani and Al-Ashraf 2012; Arunagiri and Gnanavelbabu 2014; Nasab, Aliheidari Bioki, and Zare 2015), and in aerospace (Crute et al. 2003; Powell et al. 2014; Fullerton, Kennedy, and Widener 2014, Thomas et al. 2016; Alfalla-Luque, Medina-López, and Schrage 2013). Although great lean-practice research contributions have been made in various sectors, research on lean production (LP) in the aerospace sector remains scarce; only 1.46% of the studied sample (546 companies) according to the lean review by Jasti and Kodali (2015). The reality of the aerospace industry in France is considerably different; several companies have been implementing lean practices in the aerospace supply chain for a number of years – from the aircraft manufacturer to the farther suppliers. Boeing, according to Subhadra (2003), started implementing lean practices in the nineties (first in 1997, when B737 was assembled through a moving assembly line), Bombardier applied Lean to the C series aircraft in 2003. Airbus and Pratt &Whitney are adopting the lean culture and are implementing LP approaches to sustain the ramp-up activities required by the market. Most aerospace companies

have become aware of the challenge of adopting lean implementation (Martinez-Jurado and Moyano-Fuentes 2014; Thomas et al. 2016); however, only few companies communicate lean-implementation methods and results, thus creating a significant gap in the literature. In the work of Guo (2008), the author reported the low involvement of professionals because the research contributions were mainly provided by academics. To overcome this literature gap, more conceptual research works need to be conducted and more case studies need to be investigated. Apart from the interest of the sectors in publishing more research work, Cherrafi et al. (2016) emphasized the need to expand lean practices from manufacturing to all functions of the supply chain. Jasti and Kodali (2015) highlighted the necessity to expand the LP vision to other functions, referred to as lean streams, such as LP, lean supply chain, lean product development and lean enterprise. Moreover, certain lean tools have been extensively described and widely used, whereas others have not received much attention, such as the cellular layout and visual management. Only 11.36% of published papers referenced lean cellular layout and visual management Jasti and Kodali (2015). Although extensively described conceptually, lean cellular layout and visual management have rarely been described in case studies. In the literature review of 26 lean papers, Lyonnet (2010) highlighted that visual management is rarely explored and explained. Quantitative lean tools

requiring calculations, such as value stream mapping (VSM), single-minute exchange of die (SMED), Kanban, and overall equipment effectiveness (OEE), appear to deserve greater attention because of the possibility to prove the improvement by calculation. While cellular layouts and visual management are employed for the design of a workplace, using a case study to describe and analyze these approaches is not common. We believe that these lean tools are useful in terms of the benefits generated in a well-designed workplace; thus, we consider that VM and U-shaped cells are equally important to SMED and takt time (TT). Tackled with the lack of communication about aerospace lean implementation case studies as a first gap and identified missing practices description as a second one, the usefulness of this study is to strengthen the aerospace industry findings by studying and communicating about the lean conversion to increase the knowledge in this field. A deep analysis of various lean practices is suggested to target exhaustiveness. This contribution reveals the distinctive aerospace industry characteristics and builds the more coherent lean implementation systems without misleading part of lean practices like it is often observed in the literature. The objective of this study is to demonstrate, despite the lack of examples in the literature, the suitability of lean practices for the aerospace industry based on a real complete case study that shows the link to aerospace characteristics. Indeed, in contrast to the automotive industry, the lean aerospace literature still lacks published research studies on the usefulness and targets of Lean projects. This paper addresses two specific research questions. *RQ1: Are lean practices implemented in the aerospace sector as in other sectors?* The steps of the implementation methodology and the link between the lean practices and the aerospace characteristics will be developed. The implementation methodology is a set of steps contextualized in aerospace serving as a guide to implement Lean practices. Moreover, in aerospace industry, keeping 'customer point of view' is vital to build a lean approach. *The quality and the OTD (On Time Delivery)* are targeted much more often than in other industries. The target of quality and OTD from customer point of view is crucial. Each used lean practice contributing to customer target can be split into various potential contributions to the Lean philosophy (provided through 14 Liker's principles). This last phase of global coherence checking is sturdy for practitioners because the lean principles are checked to be covered at least once by the deployed lean practice (see section 5.8). *RQ2: How the proposed methodology is able to extend the lean thinking to other services in aerospace?* It is important to illustrate through the case study how effectively the implementation of lean can be beneficial and profitable on other departments of an aerospace company. For example, a logistic department committed to lean analysis can halve their transportation costs.

The remainder of the paper is organized as follows. In Section 2, the actual findings and important observations on the lean community and the lean aerospace field will be revealed from literature. Moreover, we will highlight the various research works related to case studies pertaining to the implementation of the lean approach and their relevance to

our contribution. In Section 3, the lean implementation methodology will be described based on different steps. In Section 4, the case study and the implementation of lean practices will be detailed prior to examining the links between the practices, the characteristics, and the lean principles; the key findings of the study will be discussed. Finally, we will summarize our conclusions and we will suggest actions for our future work.

## 2. Literature review

### 2.1. Lean implementation background

In the recent review of Jasti and Kodali (2015), the authors revealed that over the past 24 years more than 45% of the published works on lean practices have mainly been published within the period 2006–2011. The same tendency was found in Rymaszewska (2016); almost 70 publications on lean manufacturing and philosophy have been published within the period 2011–2016. This tendency justifies the willingness of researchers to explore lean implementation, lean applicability, lean philosophy, lean sectors, lean services, and several other streams to specify new frontiers in the lean research area. The positive impact of lean implementation on the performance of companies has been frequently highlighted in several studies (Browning and Heath 2009; Cua, McKone, and Schroeder 2001; Fullerton and Wempe 2009; Furlan, Vinelli, and Dal Pont 2011; Jayaram, Ahire, and Dreyfus 2010; Mackelprang and Nair 2010; Nair 2006; Shah and Ward 2003). Antony et al. (2012) reported that Lean approaches are well perceived and that 63% of enterprises believe in the benefits which result from lean implementation. In the work of Laureani and Antony (2018), an international multi-sector study was conducted on 700 companies using lean and Six Sigma approaches: 66% of enterprises adopting lean and Six Sigma demonstrated success, 31% maintained the same status, and 3% failed. Netland, Schloetzer, and Ferdows (2015) confirmed the positive relationship between the implementation of lean manufacturing and the improved performance of a plant.

Very early lean application in the aerospace sector revealed the impact of lean on cycle-time reduction (Subhadra 2003; Cort 2007; Crute et al. 2008; Bombardier 2013; Thomas et al. 2016), optimizing the setup times (Crute et al. 2008). It has been reported that there has been a decrease in the defect rate and errors (Subhadra 2003), the production costs (Subhadra 2003; Cort 2007), the non-value added (NVA) activities (Subhadra 2003; Thomas et al. 2016), the time to market (Subhadra 2003), the on-time delivery (OTD) (Thomas et al. 2016), and the production space (Cort 2007). Nonetheless, the industrial reality is difficult and the lean implementation may not lead to guaranteed success. Baker (2002) reported that 90% of enterprises that implemented lean manufacturing implemented it incorrectly. Thus far, certain estimates show that less than 5% of enterprises that converted to lean approaches obtained the results they anticipated (Bhasin 2013; Vlachos 2015). Liker and Franz (2011) suggested that only 2% of lean-program implementations achieved their expected results. Interesting information

has emerged from these scientific literature surveys; data estimations have revealed certain symptomatic lean hindrances in lean implementation, such as the organizational culture (Crute et al. 2003), the resistance to change (Shah and Ward 2003; Bortolotti, Boscardi, and Danese 2015), the size of the organization (Bhasin 2013), and the lack of lean thinking (Grasso 2005). Owing to the aforementioned reasons, we believe that it is important to understand the context of aerospace to identify a relevant manner to implement lean practices. Lean success is not evidence, and it is not a toolbox. Several concepts and theories in operations management – from LP to the manufacturing strategy – have been developed through field-research cases (Voss, Tsiriktsis, and Frohlich 2002). Recognized as being a particularly applicable and powerful methodology in responding to ‘How’ and ‘Why’ questions (Rymaszewska 2016), case studies can provide a relatively full understanding of the nature and complexity of the entire phenomenon. Several authors in the literature (summarized in Table 1) have made efforts to describe, define, refine and present different findings about the performance of lean tools and the human-factor aspect in their case studies. We have examined (in Table 1) different lean case studies originating from different countries, as well as from companies of different sizes and from different sectors. The main contributions were categorized into ‘used lean tools’ and ‘human factors’, to encapsulate the new findings for practitioners. The outcomes per case study are also provided. It is interesting to note that cellular manufacturing and VM are rarely mentioned. Moreover, certain used tools as SMED have been referenced but not described in the work of Vlachos (2015). In terms of human factors, the commitment of the management has been revealed to be a powerful axis. Beyond studying the missing points of case studies literature (VM, cellular manufacturing and SMED), the human factor is of utmost importance to consider in conjunction with the technical improvements. Introducing lean practices disregarding human factors is wrong approach acting like a boomerang. For careful consideration of the human aspect, we suggest to lead anonymous survey with 33 operators over the existing production lines about the human involvement and direction’s approach in leading Lean conversion. Operators express their feelings and their opinions. Useful insights are outlined to provide practitioners a vision about the human perception and involvement in Lean deployment (described in section 6).

We also browse different references dealing with Lean practices implementation methodologies to position relevantly the distinctive points of our contribution. We kept a sample of references from 2005 to 2019; for each author main contribution is highlighted. Positive points and limitations are evoked to remind the gap and the future actions to lead (Table 2).

Foremost authors argued the necessity to implement the Lean in companies chronologically respecting identified steps (see Table 2) (Mathaisel 2005; Black 2007; Hodge et al. 2011; Panwar et al. 2015) instead of random and personal implementation, dependent on the sensitivity of the manager through PDCA (Yamamoto and Bellgran 2010). For Wan and

Chen (2009), the authors stressed that main stages have to be followed to advance the lean implantation through three stages: starting by culture, problem identification and finally implementation. Nevertheless, no guidance for lean practice steps implementation does exist and their link with the context is absent. Enumerative implementation of using tools without contextualization is a common observation (Black 2007; Wan and Chen 2009; Hodge et al. 2011). Ramesh and Kodali (2012) counter the enumerative lean practices implementation introducing the notion of AHP to prioritize some lean tools. This notion of importance of lean tools is significant for industry to guide the managers. Implementing Lean through different steps is not straightforward. It requires deeper analysis and wide consideration going beyond a simple lean implementation factors as stated in (Martinez-Jurado and Moyano-Fuentes 2014). The distinctive point of this research is threefold: (a) Structured and non-random Lean implementation steps to achieve the duplicability by other aerospace companies, (b) the implementation contribution is contextualized to aerospace, and (c) the Lean principles exhaustiveness to check whether the implemented lean tools covered the solid lean thinking and avoid asymmetric lean application.

## 2.2. Aerospace characteristics

In early studies relating to lean challenges in the aerospace industry, Crute et al. (2003) have mentioned the difficulty of this sector to align with the lean basics. However, considering the fierce competition and the evolution of the market at present, certain lean inducers have emerged, who have elucidated the adaptability of the aerospace industry in adopting LP (Thomas et al. 2016). Danese, Manfè, and Romano (2018) conducted a literature review on more than 240 papers and presented the main direction to be pursued. The link between safety and lean is an aspect to be explored; this reinforces the need to link the sector specificity to lean-production tools, which is the case in the present study. Moreover, the *sectorial characteristics* (summarized in Table 3) lead to the adoption of LP. It is *necessary, relevant* and *efficient* to maintain a competitive position in the market. The aerospace industry entails certain characteristics that need to be clarified. The following points highlight these constraints. It is known that industries such as automotive (lean origin), food and pharmaceutical have benefited from lean adoption. The aerospace sector is not an obvious application field; however, its characteristics may suggest the manner in which lean tools should be used. The literature reveals five categories that underline the specificity of the sector of civil aerospace: increase in market demand, demand diversification, product complexity, ensuring the safety and the supply chain agility. Table 3 lists information about the instigators of the lean initiative, the expected objective, the potential lean practices to be implemented, and some examples.

Presently, *market demand* has become increasingly high, thus shifting the aerospace field to an economy of high-volume production. Crute et al. (2008) reported that the

Table 1. Main contributions of lean case studies.

Lean case study literature				Main contributions of the case			
Authors	Sector	Size	Country	Journal	Used lean tools	Human factors	Outcomes
Parry and Turner (2006)	Aeronautic case	Large	USA UK	PPC	Rolls Roys and Airbus: using Visual Management ERP Output communicated to shop floor Colour coding for product division Displaying value-added information	Team empowerment to develop Need for support from Senior Manager	<ul style="list-style-type: none"> <li>Facilities communication performance</li> <li>VM cheap to produce and maintain</li> <li>Enhanced response to customer/supplier</li> <li>Bottleneck quick identification</li> <li>Increase Process Capability</li> <li>Reduced WIP</li> <li>Decrease scraps and DPU (defect)</li> <li>Reduce rework costs</li> <li>Reduce setup time – 12%</li> <li>Financial savings 140,000\$/year</li> </ul>
Kumar et al. (2006)	Automotive case	SME	India	PPC	Lean Six Sigma implementation VSM, 5S, TPM, OEE, Kaizen, 6Sigma, DMAIC,	<ul style="list-style-type: none"> <li>Top Management involvement</li> <li>Deal with employee resistance</li> <li>Convince operators that no danger for job</li> <li>Rewarded promises (Rythm 3 × 8)</li> </ul>	<ul style="list-style-type: none"> <li>Quickly self-organization: Lean workstations</li> <li>Crossfunctional teams</li> <li>Decrease inventory RM and FP</li> <li>Increase productivity (+16%)</li> <li>Clear spaces in the floor</li> <li>Increase in quality</li> <li>Pyramid Model with 6 steps</li> <li>VSM of future state</li> <li>FTR (first time right) from 98.2 to 99%</li> <li>Reduced machine downtime</li> <li>OEE increases about 17.64%</li> <li>Inventory reducing</li> <li>Defect reducing by 50% (28 valves/months saved from rejection)</li> <li>LSS approach improves Supportive activities and the manufacturing processes as well</li> <li>Standardized workflow</li> <li>Increase accuracy of data execution</li> </ul>
Chen et al. (2010)	Electric case	SME	USA	UPR	Lean Six Sigma implementation 5S, Poka Yoke, Kanban, Line Balancing, Facilities location	Mediate conflicts as team member	
Hodge et al. (2011)	Textile case	SME	USA	PPC	Lean SixSigma implementation Small batch size, VSM, 5S, Plant visits in the floor, Gemba walk	<ul style="list-style-type: none"> <li>Adopt social mechanism</li> <li>Top Management commitment</li> <li>Smooth reluctance of operators</li> <li>Training non-native English operators</li> </ul>	
Vinodh, Gautham, and Ramiya (2011)	Automotive case	SME	India	PPC	Lean SixSigma implementation + DMAIC VSM, ParetoCharts, Takt Time, Ishikawa, control charts, Design of experiments, Standards of operations	<ul style="list-style-type: none"> <li>Create a platform between the management and the employee</li> </ul>	
Wang and Chen (2012)	Mechanical case	Large	Taiwann China	PPC	Lean Six Sigma approach adopted Combined to SSM (Soft System Methodology) DMAIC approach, SIPOC/controlChart, Pareto, FMEA, 5S	<ul style="list-style-type: none"> <li>6 months project</li> <li>Understanding People needs</li> <li>Providing training and People developing competencies</li> </ul>	

(continued)

Table 1. Continued.

Lean case study literature					Main contributions of the case		
Authors	Sector	Size	Country	Journal	Used lean tools	Human factors	Outcomes
Tanco et al. (2013)	Agrofood case	SME (Chocolate)	South America	IJAMT	Lean Project: VSM, OEE, Spaghetti diagrams, work balance	6 months project Training of workers	<ul style="list-style-type: none"> <li>• Multiskills help (Cutting worker doing weighting too)</li> <li>• 40%-56% Productivity improvement</li> <li>• Poka Yoke – SMED were not used</li> </ul>
Ellis et al. (2014)	Aeronautic case	Large	USA	JOIE	VSM, Tt, 5 why, Kaizen, Taguchi experiment, standardization, SixSigma, Gemba Walk, rabbit chasing	Team gathering: Operators, Engineers, Manager 7 months time frame	<ul style="list-style-type: none"> <li>• Rework time elimination</li> <li>• Productivity improvement</li> <li>• Flexibility increase</li> <li>• Inventory reduction</li> <li>• Multiskills employees</li> <li>• Increase control of Production Schedule</li> <li>• Quick results of SMED</li> </ul>
Vlachos (2015)	Agrofood case	SME (Tea)	UK	PPC	First attempt of Lean was a failure because the objective of the supply chain defined as 'reducing inventory by a half' Used tools: SMED, VSM, Pull Strategy Lean and SixSigma disconnected projects	Collaboration with Consultants increase organizational learning Involvement of Top Management 4-year project Top and Middle Management commitment Invest in training to prepare the changes Deal with external consultants	<ul style="list-style-type: none"> <li>• Lean Six Sigma Framework is a process from the value to flexible flow creation</li> <li>• Build time reduced – 20.5%</li> <li>• OTD increase +26.5%</li> <li>• NVA reduced by 44.5%</li> <li>• Financial savings: 2 million £</li> </ul>
Thomas et al. (2016)	Aeronautic case	SME	UK	PPC	Lean tools used without strategic involvement Framework of Lean Six Sigma: QFD, VSM, Kanban, Control chart, OPT, Pull demand, DMAIC	Involvement of employees Waste identification by them	<ul style="list-style-type: none"> <li>• Focussed on welding workstation</li> <li>• Modified layout to become reconfigurable</li> <li>• Cycle time welding down from 48mn to 36mn</li> </ul>
Garre et al. (2017)	Aeronautic case	SME	India	Materials today	5S, SMED, One-piece flow, poka yoke, Layout design, inventory		

**Table 2.** Lean implementation methodologies in literature: contribution and limitation.

Authors	Main features of lean implementation methodologies	Contribution	Limitation
Mathaisel (2005)	<ul style="list-style-type: none"> <li>Defining the need for Lean practices, conceptual preliminary design, detailed design and development; implementation and construction</li> </ul>	<ul style="list-style-type: none"> <li>Steps are assimilated to PDCA</li> </ul>	<ul style="list-style-type: none"> <li>Design concept is elusive</li> <li>Not transferable</li> </ul>
Black (2007)	<ul style="list-style-type: none"> <li>Preliminary steps: train employees; involve top management; understand the financial implications; define performance measures; empower workers; define the middle management reward system.</li> <li>Operational steps: manufacturing system balancing; setup reduction; quality control; preventive maintenance; pulling materials; inventory control; integrate suppliers; automation; and design lean enterprise.</li> </ul>	<ul style="list-style-type: none"> <li>Distinction made between strategic steps and operational ones</li> <li>Human and management aspect considered</li> </ul>	<ul style="list-style-type: none"> <li>Standard lean tools enumeration for implementation</li> <li>No link of Lean tools to context</li> </ul>
Wan and Chen (2009)	<ul style="list-style-type: none"> <li>Three stages: develop a lean culture, emphasize issues (leadership commitment and use of performance metrics); implement lean practices (pull system, line balancing, VSM, visual control; implement routines</li> </ul>	<ul style="list-style-type: none"> <li>Strategic Lean culture highlighted</li> <li>Performance metrics important to check the progress</li> </ul>	<ul style="list-style-type: none"> <li>No link established between Lean tools and field.</li> <li>Only Lean tools enumerated</li> </ul>
Yamamoto and Bellgran (2010)	<ul style="list-style-type: none"> <li>Instead of having detailed steps, the focus is on creating the need for improvement and let people solve the problems using the PDCA</li> </ul>	<ul style="list-style-type: none"> <li>Steps used are common PDCA</li> </ul>	<ul style="list-style-type: none"> <li>Elusive implementation</li> <li>Not duplicable</li> </ul>
Hodge et al. (2011)	<ul style="list-style-type: none"> <li>6 steps model: policy deployment; visual management; continuous improvement; standardized work; pull production, and customer satisfaction.</li> <li>VSM supports the implementation of all step</li> </ul>	<ul style="list-style-type: none"> <li>Analysing the current state to find out the dysfunctions</li> <li>Steps are closely linked to five Lean principles</li> </ul>	<ul style="list-style-type: none"> <li>No duplicable</li> <li>No context fitting to check the validity of the lean tools constructs</li> </ul>
Ramesh and Kodali (2012)	<ul style="list-style-type: none"> <li>Four steps: identification of performance measures; identification of VSM tools; selection of VSM tool using analytical hierarchy process; and comparison of the optimum value of the metrics with real-time performance metrics</li> </ul>	<ul style="list-style-type: none"> <li>Check existing situation with VSM</li> <li>Importance of performance metrics</li> </ul>	<ul style="list-style-type: none"> <li>Notion of 'priority' interesting but difficult to duplicate in industry with AHP</li> </ul>
Martinez-Jurado and Moyano-Fuentes (2014)	<ul style="list-style-type: none"> <li>Adoption of LP is affected by a deep-rooted culture of total quality, the role of top management, a lean organizational structure, the lean leader role and institutional support</li> </ul>	<ul style="list-style-type: none"> <li>Key factors helping in lean production adoption</li> <li>Answer the question that helps to introduce Lean in aeronautics?</li> </ul>	<ul style="list-style-type: none"> <li>No answer to how implement Lean in Aeronautics?</li> </ul>
Panwar et al. (2015)	<ul style="list-style-type: none"> <li>5-step model: Employee involvement, Quality management practices, waste elimination tools, tools discrete and continuous process, supplier involvement</li> </ul>	<ul style="list-style-type: none"> <li>Human factor considered</li> <li>Steps clearly identified</li> </ul>	<ul style="list-style-type: none"> <li>No structured context fitting (e.g. Supply chain seems important in aeronautics)</li> </ul>
Marodin et al. (2018)	<ul style="list-style-type: none"> <li>Different patterns of Lean practices implementation</li> </ul>	<ul style="list-style-type: none"> <li>Lean practices performance proved in inventory, lead times, turnover</li> </ul>	<ul style="list-style-type: none"> <li>Limited impact in quality and delivery service</li> <li>Floor target (no product development)</li> </ul>
Abu et al. (2019)	<ul style="list-style-type: none"> <li>One of the main barriers in Lean implementation is the 'lack of know-how implementation' – survey addressed to 148 Malaysian companies</li> </ul>	<ul style="list-style-type: none"> <li>Identification of main motivations</li> <li>Identification of main barriers</li> </ul>	<ul style="list-style-type: none"> <li>Yet no structured lean implementation model</li> </ul>

**Table 3.** Aerospace characteristics leading to LP and examples (compilation of present authors).

Aerospace characteristics leading to lean conversion					
	Market demand	Demand diversification	Product complexity	Quality focus	Supply chain
Main Features	<ul style="list-style-type: none"> <li>• Arrival of new competitors</li> <li>• Ageing of aircraft fleet</li> <li>• Low costs arrivals</li> <li>• Opening of aviation area</li> </ul> <p>Ex: A320 competitors with the Arrivals of Chinese C919, Russian MC21, US B737</p>	<ul style="list-style-type: none"> <li>• Various requirements</li> <li>• Multiple suppliers</li> <li>• Modularity concept</li> </ul> <p>Ex: A350 was developed on 3 versions and 5 variants to reduce diversity impacts on production lines</p>	<ul style="list-style-type: none"> <li>• High data volume</li> <li>• Multitude operations</li> <li>• Long assembly delay</li> </ul> <p>Ex: Dauphin helicopter – Eurocopter is made up of 10.000 components with more than 800 operations</p>	<ul style="list-style-type: none"> <li>• RFT Right First</li> <li>• Time strategy</li> <li>• Keep reduced 1st tier suppliers with collaborative relationship</li> </ul> <p>Ex: Lithium-ion Battery conflagration in Japanese airline B787 (in 2014). Specific focus on quality is required.</p>	<ul style="list-style-type: none"> <li>• Ensure the availability of raw materials/sub-assemblies</li> <li>• Reinforce multisourcing strategy</li> </ul> <p>Ex: Supply chain department creation at zodiac aerospace to standardize the purchasing needs from all the production lines.</p>
Authors	Crute et al. (2008), Davies, Coole, and Osypiw (2006)	Gingerich (2011), Chang, Huang, and Torng (2013)	Reitermeier (2004), Haque (2001)	Reitermeier (2004), Garrido-Vega, Sacristán-Díaz, and Magaña-Ramírez (2014), Crute et al. (2003)	Davies, Coole, and Osypiw (2006), Johns, Crute, and Graves (2002) Crute et al. (2008), Chang, Huang, and Torng (2013)
Objective	Sustain the ramp-up Get a competitive advantage in the market	Ensure the production of the different versions	Sustain the reliability of the product	Ensure the quality of the product	Ensure the efficiency of the supply process to respect OTD
Lean issues	Continuous flow VSM Takt Time Gemba walk	Setup times reduction Flexible lines Cellular layouts Visual management	Visual management Waste elimination (moving line) 5S and standardization Pull system	Multiskills employees TQM, OEE JIT production Poka yoke One-piece Flow	Kaizen JIT purchasing Supplier involvement
Examples	VSM at Airbus UK (Davies, Coole, and Osypiw 2006) Threat of new entrants (Martinez-Jurado & Moyano-Fuentes 2014)	Setup times reduction (Crute et al. 2008) Flexible production lines (Gingerich 2011) 5S/TPM/VM and SixSigma (Thomas et al. 2016) Visual Management (Davies, Coole, and Osypiw 2006)	Moving lines Boeing B737 (2 inch/mm) (Subhadra 2003) In Chang, Huang, and Torng (2013), B747-2001 from 24 to 18 days, at Airbus (1 m/h) and C-series moving line (Moknine 2014) 5S/TPM in Aerospace Shopfloor (Chang, Huang, and Torng 2013)	One-piece Flow Poka yoke and SWI (Cort 2007) One-piece Flow (Davies, Coole, and Osypiw 2006), (Subhadra 2003) Worker empowerment (Moknine 2014) and employee involvement (Altfield 2010)	Kaizen and Kanban used at CAE Canada (Moknine 2014)

main lean motivation, as mentioned in interviews with aerospace companies, is to meet the increasing demand of clients. Martinez-Jurado and Moyano-Fuentes (2014) specified that the pressure of being competitive is the triggering element that leads companies to implement lean initiatives. To respect this market-demand pressure, a suitable rhythm of production should be identified. Davies, Coole, and Osypiw (2006) reported that Airbus UK found it useful to use the following lean practices: VSM to identify the bottleneck resource and the work in progress (WIP), VM to clarify the rhythm of the production and to address the market demand. The *demand diversification* is an additional complex point which companies are required to address; this urges them to adapt their production system quickly to absorb the fluctuant and diversified demand (Slomp, Bokhorst, and Germs 2009; Browning and Heath 2009). Gingerich (2011) mentioned the importance of creating flexible production lines to address various orders. Chang, Huang, and Torng (2013) argued that aircraft manufacturing suppliers should increase the flexibility in the production line to address the dynamic demand. This diversity in the demand does not tolerate approximate deliveries. The reactivity and flexibility are solid enablers provided by the LP.

An aerospace product – whether it is an aircraft or a lock-bolt – is obviously a complex artefact (Reitermeier 2004) requiring fitting with requirements, specifications and regulations. In such a complex product, the manufacturing time and assembly cycle may increase the time to market. Lean practices, such as VM to reduce the errors and the elimination of waste, have become interesting tools. In large facilities, such as aerospace facilities, the motion and movement times require waste elimination, starting from the assembly and extending to the new product development (Reitermeier 2004; Haque 2001, 2003; Davies, Coole, and Osypiw 2006). Safety in the aerospace sector (ensured by means of extreme quality) is specific to the products that should be *right first time (RFT)* (Crute et al. 2003; Reitermeier 2004) and are almost defects free. Garrido-Vega, Sacristán-Díaz, and Magaña-Ramírez (2014) argued that ensuring the safety of the provided aerospace product is of utmost importance. The idea of lean one-piece flow becomes interesting, and it is a suitable concept for each manufactured part. Lean practices such as the poka yoke and the standardization of instructions are approved as a means of establishing a coherent production (Cort 2007). To simplify the production process and the assembly of aerospace parts, several focal companies outsourced their products. The more a product is modular, ultimately the more likely it is to fit the market diversification and efficient supply chain (reduced versions and variants in the Airbus portfolio). Davies, Coole, and Osypiw (2006) reported that Smith industries used the modularity concept (common subassemblies) to reduce the market to client time; thus illustrating the importance of agile supply chain. Moreover, Johns, Crute, and Graves (2002) stated the necessity of moving towards a lean supply chain to sustain a competitive advantage (Crute et al. 2008). The various aerospace characteristics will guide the analysis throughout the case study for the purpose of illustrating the degree to

which they need to be respected in the implementation model.

### 2.3. Research methodology

In general, the research papers belonging to operations management tend to contribute to existing theories, or use existing theories to explain phenomena management even if the development of a new theory is difficult (Boer et al. 2015). Our paper is rather exploring and extending the existing theories, i.e. in our research, the exploration and extension of existing lean techniques based on specific theories. In the book about operations management research methods in Karlsson (2016), two researches axes co-exist to contribute to theories: exploratory studies and confirmatory studies to test and extend theory. We can position our contribution in the second axis to complement and extend theories, i.e. lean techniques based on theories in this paper. Regarding the research type used in this paper, we develop a descriptive model with the aim to be transferable. The methodology can be qualified as exploratory to link the different elements of analysis towards repeatability when implementing the lean in aerospace assembly lines. A qualitative research, descriptive and exploratory, contributes to complement empirical investigations often led in the literature (Seaman 1999). This research uses qualitative method; specifically, an in-depth case study. A key strength of using a qualitative approach is to explore research questions and go beyond finding evidence of a relationship, to revealing 'how and why' that relationship might exist (Yin 1994).

The use of multiple sources of data is a way to improve the 'validity' and 'reliability' of case study findings (Karlsson 2016). Data used in the case study are provided from structured and unstructured interviews, company documents, formal debriefing, status reports and surveys. Individual interviews were conducted lasting 30–60 min and weekly ensured during 6 months to perceive and understand the flow of products. A team member ensured data collection directly on site. Two other members of the research team were in charge to ensure the transcription of data. In addition, the correspondent took notes to record impressions, outline the observations from the facilities inspected. The data collection undergoes an immediate transcription and accuracy checking for transmission to research centre. The interview protocol included multiple respondents, facilities and production line data sources, plant visits/factory tours. Various respondents interview was a careful consideration to ensure the construct validity. Statements made by the management were also added. Three production lines in different facilities were under observation to gather data about the workstation information, the succession of operations from raw materials to final product, the quality inspection and the references changeover. Data analysis resulting from the interpretation, experiences and different events allows the depth to understand how lean deployment can be influenced by the aerospace sector context.

### 3. Methodology for lean-practices implementation in the aerospace context

Recent publications have highlighted the necessity to develop models for helping lean practitioners to implement lean manufacturing. Mostafa, Dumrak, and Soltan (2013) emphasized the necessity for simplified and comprehensive implementation frameworks. Dora and Gellynck (2015) highlighted the still-missing straightforward approach: *There is no clear, standardised, easy-to-use framework for a lean manufacturing practice implementation available*. Almani et al. (2018) remind recently that there is still challenge to create guidance to the Lean journey. Pavnaskar, Gershenson, and Jambekar (2003) reported that lean tools have not been thoroughly understood, which may lead to misapplications and ineffectiveness. In the present work, we will attempt to define a relevant methodology for the implementation of lean practices, specifically in the aerospace field.

The proposed model was based on the assumption that meaningful aerospace characteristics need to be addressed and sustained by an appropriate set of lean practices. The use of a conceptual model in a normative manner will ensure coherence of the lean project deployment. Before planning and initiating lean actions, it is important to define the value from the perspective of the customer (first principle of lean) to make the correct efforts. The *safety/quality of the product* and *OTD* were defined as the priority values, which are expected by the customer along the implementation process.

Figure 1 illustrates the different steps of suggested PTPC-AS/LF for the initiation of lean implementation in accordance with the defined values. PTPC-AS/LF is Plan, Tools implementation, Performance review, Continuous improvement – Aerospace Characteristics (AS)/Leanness Fitting (LF). PTPC can be assimilated to the classical PDCA but the association of PTPC to AS/LF creates a distinctive augmented PDCA approach.

Step 1 is the plan 'P' of Lean implementation action. After a Gemba (Ballé and Beauvallet 2013) which reveals the dysfunctions, the 'plan' targets to map the processes with its value-added activities and NVA activities; the VSM in the initial situation appears to perceive the axis of improvement.

Step 2: 'T' consists of identifying the different lean tools to implement for operational and product flow performance. The following lean technics are applied and described along the case: *U cells, one-piece flow, standardized work instructions, poka yoke, SMED, VM, TT and multiskills*. The 'check' phase allows the identification of the impact of the undertaken lean practices through the scraps rate, the cycle time, and the costs. It comprises the analysis, which is the second layer to check the correlation between the set of implemented lean practices and their contributions to the aerospace characteristics. The aim of this step is to perceive the usefulness of each lean tool to cope with *market demand, diversification, safety, complexity and supply chain*. In Step 3, 'P' Performance Review aimed at checking the generated performance. We argue that it is not enough to check operational performance when Lean practices implemented, it is also crucial to perceive the lean principles exhaustiveness

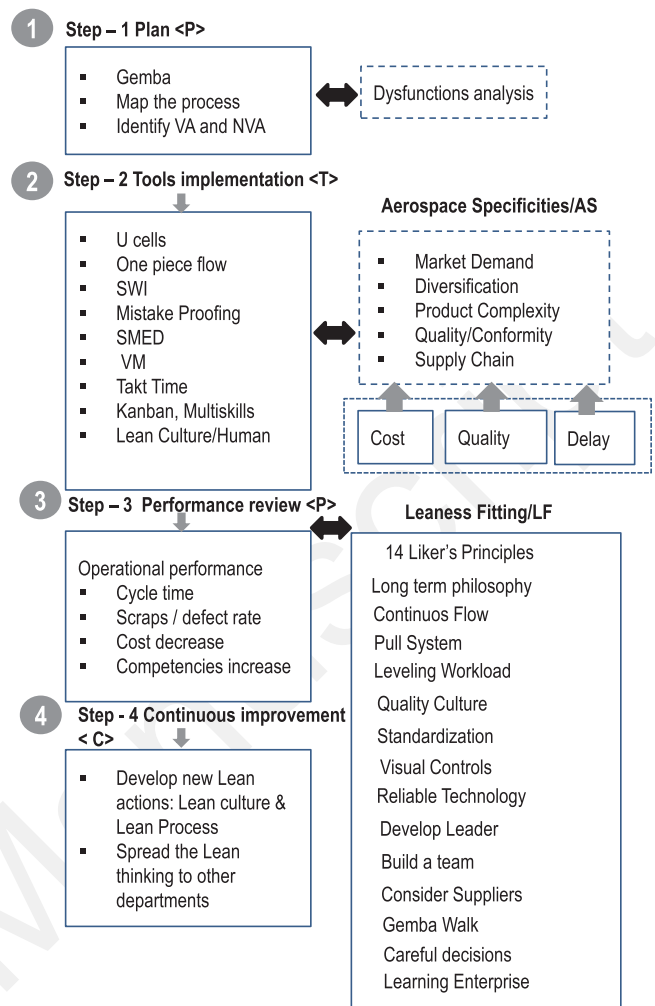


Figure 1. Methodology PTPC – AS/LF of lean implementation in the aerospace industry.

and understand whether the implemented lean tools are fitting the lean principles. The lean implemented practices should be associated with 14 lean principles (Liker and 2004). It means the adequacy between the used tool and its contribution to principle satisfaction. In Step 4, the continuous improvement is the loop to join the 'act' in the PDCA phase. It is important to examine new opportunities to expand lean thinking and use the different services to extend it. The logistics department will be used as an example to show the benefit of lean transportation that follows the LP.

The described methodology is required in the aerospace industry because the observations lead to a thorough consideration of the context. However, the approach is replicable to other sectors by respecting Steps 1–4, even if the outcomes of these steps will obviously be different depending on the sector in which they are applied. More specifically, the result of Step 2 and the characteristics are dependent on the field and size of the company. This methodology is valid for the aerospace industry in general; however, it may also vary for each company in Step 3. Each company is able to define its own lean progress. Some refined adaptation of the methodology may be required and it is recommended that it

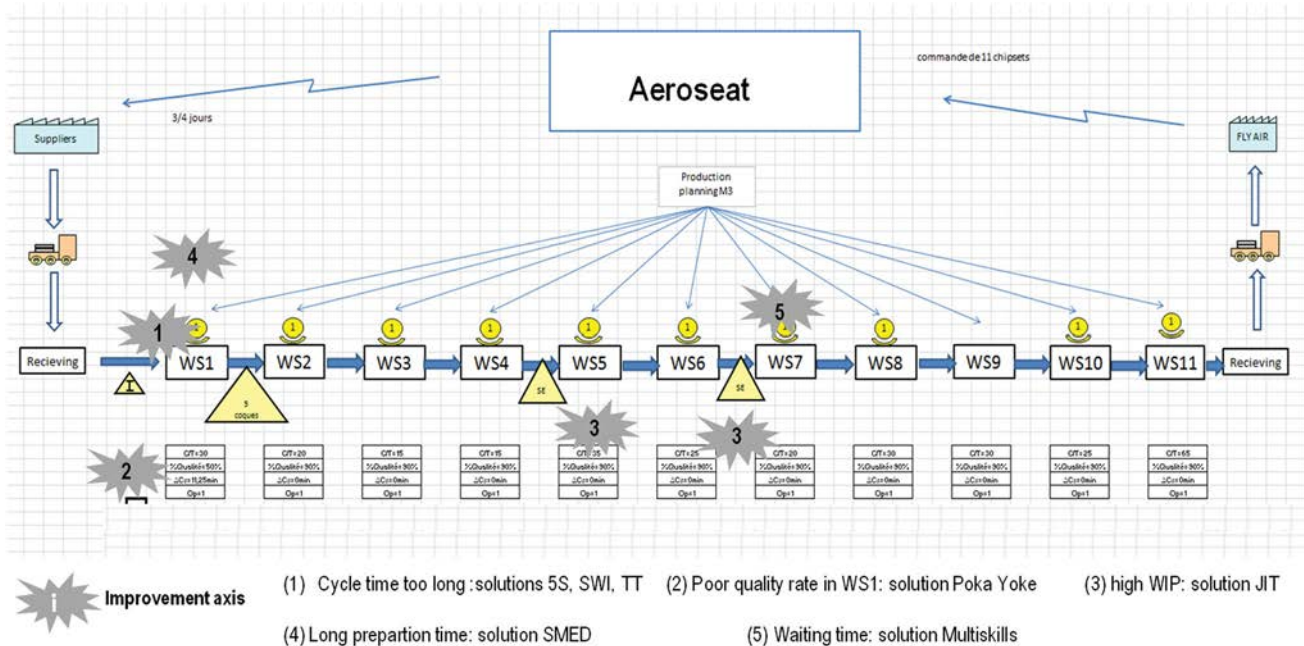


Figure 2. VSM for the assembly line at Aeroseat.

fit the field in the best manner; nevertheless, it remains useful for the guidance of managers in the implementation.

#### 4. A case study: the aroseat company

The studied aerospace company will be referred to as *Aeroseat* throughout this paper. The *Aeroseat* products may be divided into three categories: *business*, *economy* and *crew seats*. The company is large, with more than 1500 employees. The network consists of different electronics suppliers, machined parts, composite manufacturers, paint suppliers and clients (e.g. Boeing, Airbus, Dassault, AirFrance and Emirates). The competition among the aerospace suppliers is growing along with the increase in aircraft demand owing to the opening of airspace, the launch of low-cost companies, and the aging of the air fleet. The focus is on the *business class seats*, referred to as *BC1*, intended for the *Flyair* company, with which *Aeroseat* is committed with a one-year contract to deliver seats for 11 aeroplanes (referred to as *shipsets*). The *shipset* encompasses 46 *BC1* seats. The *economy* and *crew seats* are out of the scope of the present study. *BC1* is produced on two different assembly lines based on two production sites: one is dedicated to the seats and the other is dedicated to the shells. The seats and shells are sent separately to the customer, who will then assemble them during the installation in the *shipset*. In this study, we will focus on the assembly line of the shells based on one production site.

The actual VSM (Figure 2) provides useful quick information about the product flow progress. The VSM is a powerful tool to help the decision manager to carefully direct his attention to address emerging issues. The quick-improvement axes have been identified: (1) the long-cycle time has often been noticed at the beginning of the flow (*WS1*). The poor quality rate was responsible for the incomplete or defective

assembly requiring a rework on the assembled seat. A high WIP overloaded the space of work before *WS7*. Long setup times occurred before shifting to a different seat reference (at *WS1*) because of the long preparation of the materials and tools. Long waiting times occurred in *WS7* because the allocated resource became a bottleneck, which blocked the progress of the flow. These first observations associated with the following description of the implemented lean tools are the basis for product flow improvement.

#### 5. Lean practices implementation – details and results

##### 5.1. One-piece flow and cellular layout

The *BC1* seat assembly was performed following the make-to-order (MTO) process. *BC1* consisted of the supplied parts (controlled at arrival from the supplier) and the subassemblies, including the TV, panel and the map light (prepared in a dedicated area). The seat was assembled along 11 successive workstations. Each worker was dedicated to each workstation. There was no WIP between the workstations. *WS1* to *WS11* were assembly workstations; *WS6* and *WS10* were electrical and electronic wiring workstations with specially trained, qualified workers – no error would be tolerated. Two final quality inspections were required to validate conformity: one performed by *Aeroseat* and the other by the customer inspector (Figure 3).

The actual strategy was to keep an amount of subassemblies that would be required on the next day to be put in front of the line at the beginning of the day. When the product is stated as defect-free, it would be directed to expedition. The *Gemba* revealed that *WS7* is the shop where the subassemblies are assembled. They move from the warehouse through the entire plant. A possibility of certain WIP

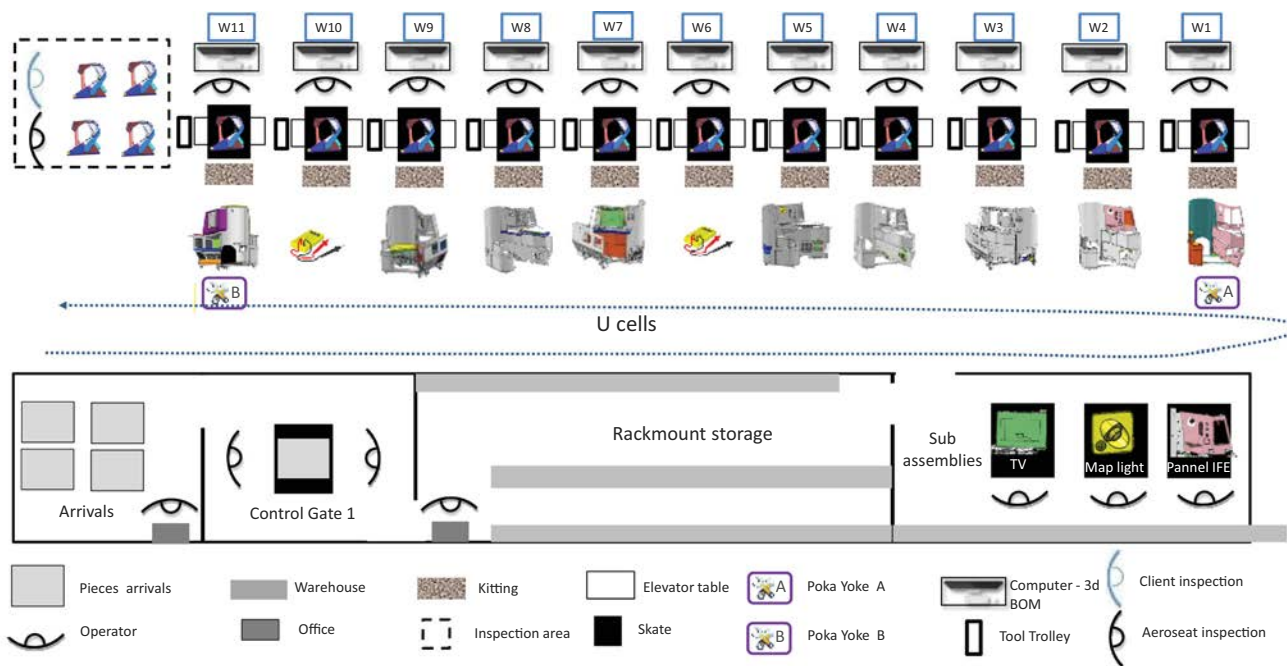

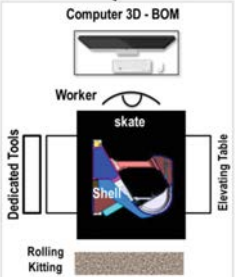
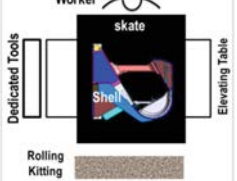




Figure 3. Cellular layout of the shop floor.

Table 4. Visual management for the design of the WS.

Visual management – how the work station is designed?

Visual management – how the work station is designed?	Feature	Contribution	NVA decrease
	Computer 3D – BOM	Dedicated place (behind the worker in front of wall) Check the validity of the assembly process viewing the shell's components through BOM	Eerrors of assembly requiring reworking times Components waste in the false assembly
	Skate Elevating Table	Supporting the volumetric product Worker Comfort consideration	Damages of product during the transportation Ease the transportation for workforce Diversity of movements seeking the right position for assembly Discomfort and absence
	Rolling Kitting	Parallel yellow paintings in the shop floor to guide the kitting Sustaining the moving line production by rolling kitting Dedicated boxes kits/workstation to avoid confusions	Risk of wrong components for the workstation coming from other places. All components are in the right floor of the Rolling Kitting and they move away with the shell trip along the 11 workstations
	Tools Trolley	The whole tools/equipment are put together and dedicated to each workstation	Tools confusion Long-time tools seeking
	Worker	One worker dedicated per workstation	Dedicated resource focussing on each WS

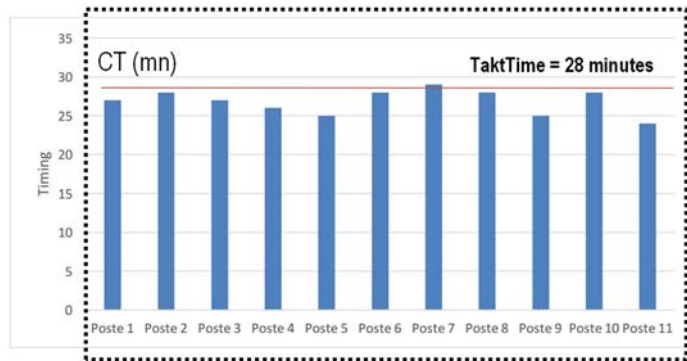
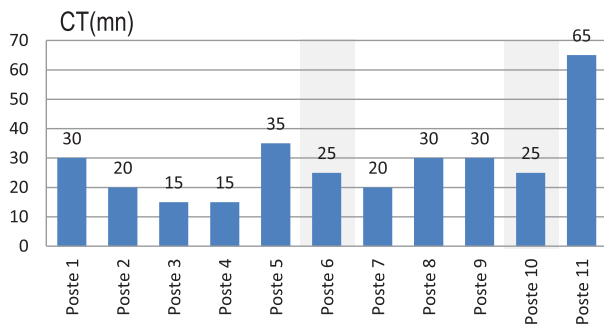
for subassemblies near WS7 is excluded, owing to the lack of space around WS7 and the risk of damage (volumetric product and technically complex). The idea of the pull-system implementation with Kanban cards would be an interestingly welcome solution. Kanban may help to illustrate to the warehouse manager the necessity of bringing the subassemblies right where the cards are coming back, triggering the necessity to re-supply WS7 in a just-in-time continuous flow.

## 5.2. Visual management (VM)

Each worker was assigned one WS to execute one piece at a time. Several dysfunctions were observed, such as checking

the tools and running to bring equipment. A careful analysis was performed to build a convenient workplace based on the VM principle with the objective of being able to quickly obtain the right tool from the right place at the right time (Table 4).

The shell (volumetric and heavy product) was placed on a 'skateboard' to allow easy manipulation and transport from one WS to another. In addition, an 'elevating table' was suggested to create ergonomic work conditions at the level of the worker. Each WS included a dedicated tool box which was placed on the right side of the worker. A computer was placed behind the worker, where he could check the 3D plans of the shell, and the bill of materials (BOM) to check the components to be assembled. The 'visual paintings' on



Daily capacity: 8h/day (60 minutes break)  
 Monthly capacity: 20 business days  
 Monthly demand: 300 shipsets  
 Daily capacity =  $300/20 = 15$  shells/day  
 $TT = NOT/CR = (7h * 60)/15 = 28$  minutes  
 WS5 and WS11 are important to leverage

Levelling production  
 $11 \text{ workstations} * TT = 11 * 28 = 308$  minutes  
 Excluding WS6 and WS10 =  $2 * 25 \text{ mn} = 50$  minutes  
 The remaining time =  $308 - 50 = 258$  minutes  
 To spread over the remaining 9 non critical WS:  
 $TT \text{ targeted} = 258 / 9 = 29$  minutes

Critical work station WS6 and WS10  
 $CT_6 = 25 < TT$  and  $CT_{10} = 25 < TT$

Levelling production to the TT

CT: Cycle Time

NOT: Net Operating Time

CR: Customer Requirement

Before Levelling Production

After Levelling Production

Figure 4. Levelling of the production with TT.

the floor illustrated the correct positioning of the 'rolling kitting' dedicated to the shell. Indeed, a dedicated kitting was prepared for each specific reference of BC1 since the beginning of the process using visual identifications. This kitting was then manually rolled by the worker through the parallel yellow floor painting and was dynamically moved immediately when the shell was moved to the next WS. The non-conforming product assemblies were significantly low, and the NVA activities were consistently reduced in the WS.

### 5.3. TT and levelling of production

Regarding the initial data of the cycle times (CT) obtained at each WS, Aeroseat experienced a desynchronized production flow, generating waiting times at a certain WS. This created unsafe situations, e.g. shutdowns on WS6 or inventories waiting to be processed at WS11, which may consume almost 1 h to be fulfilled (see Figure 4). Next, the production was organized to meet the order of Flyair with OTD. The overload and bottleneck resource was identified; it was observed that WS11 clearly created high waiting times, thus Worker 10 was idle. To levelling the production, sales and operations planning (S&OP) data were first analysed. The analysis showed that the total number of shells to be produced per month (all types and clients) was 300. This was the maximum capacity that Aeroseat could achieve. The initial situation in Aeroseat presented various cycle times, without any takt-time target to respect. A calculation was performed to reinstate the plant assembly activities to the accepted level.

In fact, only WS6 and WS10 were considered as critical workshops for inspection and control to ensure the validity of the product. TT was calculated to be 28 min. The critical workshops should be stabilized to the actual rhythm (25 min)

and the remaining workshops should be improved to come as close as possible to the targeted TT to regulate the production flow. The leveraging resulted in a bottleneck reduction and a continuous-flow progress.

### 5.4. Standardized work instructions (SWIs) and digital support

Structured instructions for the cycle time duration, chronology of tasks and used tools were issued and stored inside a physical file on the right side of the worker. For traceability reasons and information completeness, digital work instructions (WIs) were also provided on the computer. Indeed, to avoid assembly errors, each worker had access to the bill of materials (BOM) of the product and 3D information on the computer (located at the edge of the workstation). The BOM showed what the shell was composed of, and the manner in which the different components should be assembled. The method department provided the workers with the SWIs. Two versions were deployed (Figure 5); the first method was considered as not fully reliable, with a risk of being inaccurate owing to the use of a colour code on the SWI. In fact, the removal of the colour code on the screws was ordered by the company for quality reasons as per ISO 9001 to ensure that a *colour-blind worker* would be able to easily read the WIs without any risk of perceiving the screw colour incorrectly. The addition of security alerts is necessary to remind workers of the most frequent assembly problems and to avoid recurrent errors. Visual signals were used for the alerts.

The SWIs allowed the regulation and the respect of the steps; however, several other disruptions were observed. Each shell was volumetric, specific, with great technicality

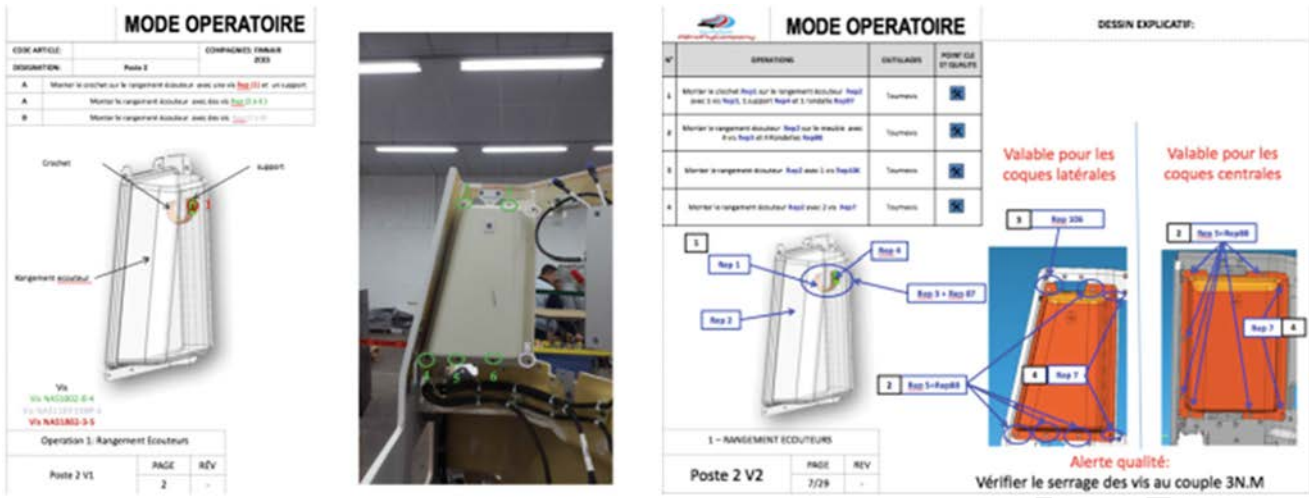


Figure 5. Standardization of work instructions: Version 1 SWIs (left side) versus Version 2 SWIs (right side).

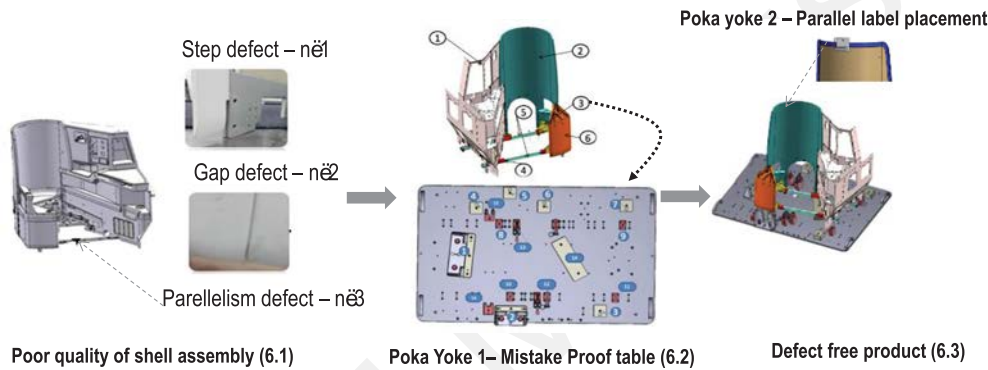


Figure 6. Poka yoke for WS1.

and high value. One can expect a 100% uptime in each WS owing to the one-piece flow, the SWIs and VM. Nevertheless, close observation revealed that the products were not confirmed. Unfortunately, this manifested from the beginning of the process. More specifically, problems occurred in WS1. A problem resolution was initiated on how to increase the quality rate at WS1 to downplay the perceived defect rate.

### 5.5. Poka yoke: mistake proof

In WS1, the beams that held the shell in the aircraft and the coupling of the backshell were assembled with the armrest. When a defect was detected, the next step was to control, inspect and rework the entire shell to revert it to the conformity level. Moreover, if inspectors detect problems caused by WS1, it may be too late to rework the product that had undergone additional added values (from WS2 to WS11). Therefore, the objective is to realize *RFT* accurately at an early production phase. The idea is to identify the types of non-conformity before checking the solutions. Three types of defects were identified (Figure 6): (1) Step error: height defect between the backshell and the bounded structure, (2) Gap error: width defect in the backshell, and (3) Parallelism error: between the two beams.

To increase the quality of the process, make WS1 reliable, and escape the burden of reworking, lean thinking

allowed the design of an adapted mistake-proofing tool to achieve RFT. A poka-yoke tool is able to immediately recognize if the process is meeting the requirement. Therefore, a positioning table was designed, which is a type of table where different slipways (fixed with screws) have to be assembled in certain directions to permit the accurate positioning of parts. A fitting check was possible during the assembly process. Through this perspective of achieving the RFT via poka yoke, a well-assembled shell (with perfect gap fit, perfect step fit, and parallelization insurance) allows convenient assembly on the aircraft. An additional small defect (unacceptable from the perspective of the client) was detected at WS1, namely a defective label deviation. The idea was to design a simple poka yoke N°2 for label placement that could be fixed over the backshell and would provide the necessary parallelism regarding the edge. The described poka yoke for the placement was a small piece of equipment that was designed internally and then 3D printed.

### 5.6. SMED: setup times reduction

The one-piece flow policy in Aroseat involves working with the same shell along the different WSs until the piece is validate and shipped; in this context, the SMED lean practice seems pointless. However, a significant amount of waste was

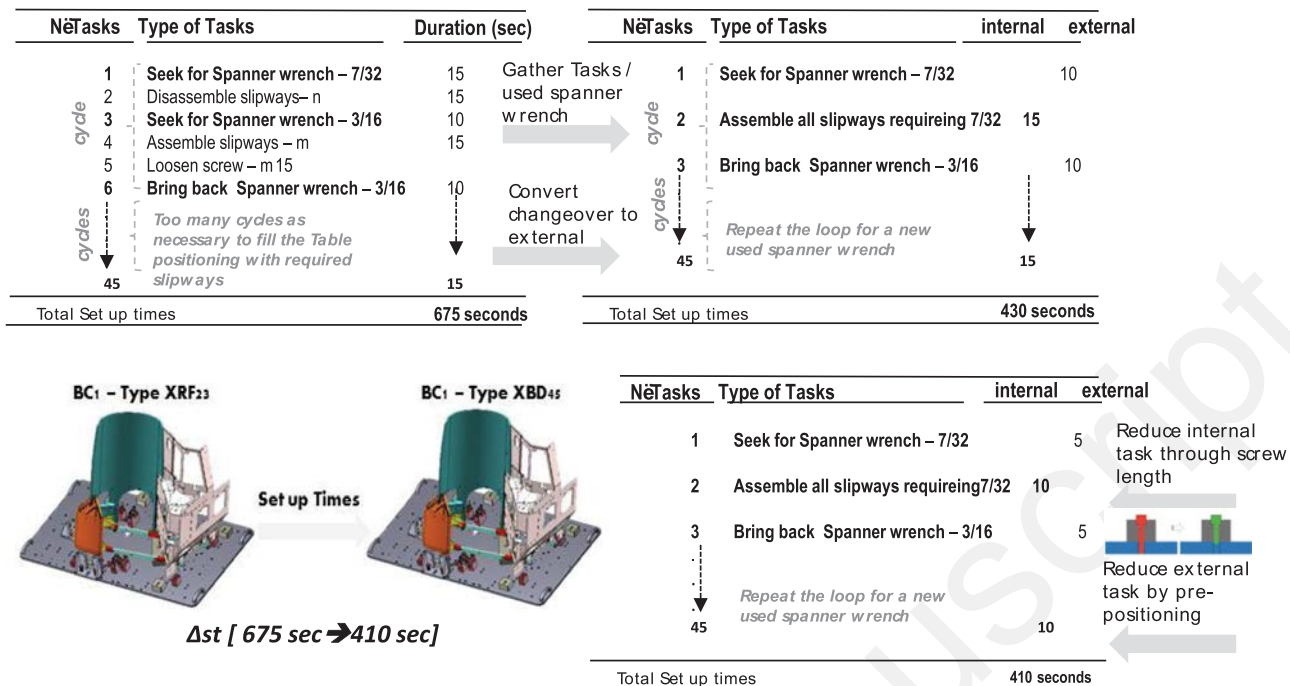


Figure 7. SMED application for BC1 model.

produced during the assembly. It should be noted that 46 types of shells may be provided for one shipset. For the same aircraft, 16 types of shells exist among the 46 possible shells provided. This important diversity needs to be considered when changing the shell reference assembly. WS1, which is in charge of the first step, should accurately assemble the chosen type of shell. A careful positioning of slipways on poka yoke N°1 is necessary to avoid assembly defects (gap, step, parallelism). The diversification of shells should be supported to switch from one type to another with a high reactivity and high ability of reconfiguration.

The setup times are induced for the preparation of a specific positioning table as per the reference of the shell. The positioning table should contain the correct slipways configurations: *spanner wrench changes, screwing specifications, respect of pace between the parts, and their tilt inclination*. These actions of configuration are obviously time-consuming; thus, the implementation of SMED is desirable. For instance, to build reference BC1-XRF23, 45 operations were enumerated by the team. Upon detailed analysis, these mainly concern the picking up of the snapper wrench, the assembly of the screws on the slipways to make them fixed, and bringing back the snapper wrench. Several positionings need to be installed on the table; therefore, cyclic tasks are repeated as many times as necessary to provide the full building of the slipways and to allow the start of the process at WS1. In fact, the setup times of 45 operations require 675 s. Figure 7 summarizes the progress of the setup-time reduction at each step.

The idea is to *transform the internal operations to external ones* (bring the snapper wrench and take it back required 10s, which could be saved if the procedure was performed externally). Next, it becomes necessary to *combine a set of operations*, e.g. the operations requiring the same snapper wrench (7/32). The installation of all the slipways that

required the use of the same tool was performed before moving to a different one. The final step would be to *reduce the internal operations*. Discussions with the team have also resulted in the reduction of the length of the screws. Longer screws require more time to fix the slipways. The team suggested *reducing the length of the screws*; this was sufficient to create a fixation for positioning the shell. In this manner, 5 s was saved owing to the length reduction. The last step of SMED was to *reduce the duration of the external operations*. The team proposed a pre-positioning of the suitable snapper wrench to reduce the unitary value from 10s to 5s. As shown in Figure 7, once the four steps of SMED were initiated, the setup times dropped from 675 s to 410 s.

To obtain an appraisal of the potential overall financial gain, different parameters should be considered: *the number of possible changeovers of shell characteristics (16 types), the TT and 11 shipsets of the Flyair contract*. The details are provided in Table 5: for the Flyair contract, 87,500 € could be saved owing to the optimization of the setup times.

### 5.7. Multi-skilled employees: empower and increase competencies

To increase the reactivity of the company, workers have been trained to be multi-skilled because cross-functional abilities are, at present, the guarantee of continuous flow in case of disruptions, such as absence and illness. The exception is noticed in WS3, where a dedicated worker is assigned because of the specific knowledge required in electrical and electronic wiring. This knowledge is difficult to replace because it requires a strong background and experience. Aroseat employs two different types of workers: specific agents (permanent contract agents), who master key trades and temporary workers, who are hired for a period of

**Table 5.** Financial gain assessment after SMED implementation.

WS1 – setup times optimization ( BC1 – XRF23)		
Initial data	Before SMED	After SMED
11 Shipsets	T = 675 (sec)	T = 410 (sec)
16 Shells references		Gained time = 265 (sec)
11 Workstations WS		Total gain time = 265 sec × 16 shells × 11 WS = 777 min
TT = 28 min		Gained products = 777/308 = 2.5 shells
1 shell = 28 mn × 11 WS = 308 mn/shell		Financial gain = 2.5 × 35.000 = 87,500 euros
1 Shell price= 35 K euros		

**Table 6.** Lean practices correlation with aerospace characteristics.

Lean practices	Aerospace characteristics				
	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5
U cells	1	1	1	1	1
One-piece flow	–	1	1	1	–
Visual Management	–	1	1	1	1
Standard work instructions	–	1	1	1	1
Takt Time	1	–	–	–	1
Poka yoke	–	1	1	1	–
SMED	1	1	–	–	1
Multiskills	–	1	1	–	1

Spec. 1 – Market Demand; Spec. 2 – Diversification; Spec. 3 – Product Complexity; Spec. 4 – Safety/Quality; Spec. 5 – Supply Chain Agility.

18 months with the option of flexibility, according to the evolution of the order book. The two types of workers were trained to have a versatile position.

### 5.8. Analysis of lean practices correlation with aerospace characteristics and leanness fitting

The set of aforementioned lean practices should be correlated with quoted aerospace characteristics, the increase in market demand, demand diversification, product complexity, safety and quality requirements, and supply-chain agility. The following figure captures the contribution of each tool to each characteristic (called also: specificity, ranging from Spec. 1 to Spec. 5). The U cell is a lean technic able to contribute to easily absorbing the market increase in linear and successive operations with an ability to face the diversity of the product, if flexibility is ensured in the production line. The complexity of the product would be better managed through clear production steps in the U cell. A clear production space is also a mean of ensuring assembly quality, because crossing flows are prevented. A supply chain requiring reactivity is sustained with clear and optimized production steps. The one-piece flow technique, VM, poka yoke and multiple skills are similarly correlated with aerospace characteristics, except for the market demand and the supply chain, which are independent from the product batch, the internal VM and the mistake proofing. SMED is adequate to cope with the high market demand and with the diversification of references, thus ensuring to fulfil different customer supply chains. TT is a regulation of production rhythm that can help to ensure market demand ramp-up and supply chain agility. All aerospace characteristics are covered by at least two lean practices (Table 6). If specificity seems to not be covered, it means some lean practices are missing and have to be

found. If imbalanced correlations exist, it means new tools have to be checked and tested to cover maximum characteristics. The objective of this step is to ensure lean tools have been adapted to the context. Lean practices can be ranked according to meaningful lean tools. The managers can calculate an assessment of Lean practices priority through suggested index – *FLP: Factor of Lean practice* (see Table 6). The maximum FLP calculated over the 8 lean tools will be assigned the first rank (R1) in priority of implementation because of closeness with aerospace context.

$Corr_{sp} = 1$  if Lean practice is positively correlated to aerospace specificity

$Corr_{sp} = 0$  (noted-) if no correlation

Wsp: is the weight that can be assigned a value by a manager to discriminate the importance of aerospace characteristics if judged not equally important.

$$FLPi = \sum_{sp=1}^5 Wsp. Corr sp \mid i = 1.8$$

$i$  the number of Lean practices to implement. Ranking of Lean practices priority:

Highest value of Lean practice factor (Rank 1):  $R_1 \leftarrow \max \sum_{sp=1}^5 Wsp. Corr sp \mid i = 1.8$

The correlations are found and discussed with the case study team. The details may be checked in Appendix 1. The results of our assessment considering that the weight of all characteristics is equal to 1, shows that:  $FLP(U\ cells) = 5$ , it means U cells is assigned the first ranking in terms of importance R1.  $FLP(VM) = FLP(SWI) = 4$ .  $FLP(One-piece\ flow) = FLP(Multiskills) = FLP(SMED) = FLP(Poka\ Yoke) = 3$ . The Takt time is the last one  $FLP(Takt\ time) = 2$  and is considered as the less prior Lean practices. Appendix 1 reveals the interview results gathered and summarized from the case study.

In Table 7, we highlight to what extent the aforementioned lean tools implemented in the company contribute to achieving the lean philosophy through the 14 principles of Liker and (2004).

All principles are considered at least once. It is important to state that the use of lean practices is a guarantee of firmly linking each lean tool to at least one principle of lean. Anarchic use of lean tools is occasionally useful, but may often collapse because of the lack of a global lean coherence. Using this table, we may examine the correspondence

Table 7. Contribution of the lean practices to the 14 principles of Likers: leanness fitting.

Key achievement	Contribution to lean philosophy – 14 principles of Liker and (2004)													
	Long term philosophy	Continuous flow	Pull system	Levelling workload	Quality culture	Standardization	Visual controls	Reliable technology	Develop leader	Build a team	Consider suppliers	Gemba walk	Careful decisions	
Visual management	✓	✓	✓	✓	✓		✓							
One-piece flow	✓	✓	✓	✓	✓			✓						
Work standardization	✓	✓	✓	✓	✓	✓								
Poka yoke		✓	✓	✓	✓	✓								
Plant layout – U cells	✓	✓	✓	✓	✓	✓								
SMED		✓	✓	✓	✓									
Multiskills	✓	✓	✓	✓	✓			✓	✓					
Management							✓			✓			✓	

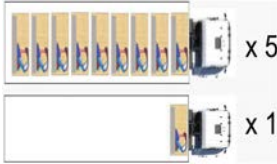
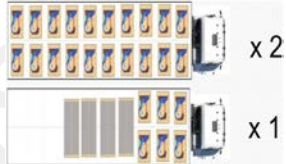
and the coherence of the lean-tool choice with the lean philosophy. This is expected at each step and is useful for practitioners to ensure safety and balanced lean principle consideration, and that their lean projects are following the right direction. Certain distinctive principles seem widely supported, such as *continuous flow*, which are sustained by all lean practices that contribute to ensuring the non-interruption of the flow and the optimization of its progress. The *quality culture* is also well supported by the lean practices in which 'RFT right first time' is performed: VM, one-piece flow, work standardization, poka yoke and the U cells. *The levelling of production* is also supported by VM, one-piece flow, multiple skills and SMED. When we introduce the concept of Leanness fitting, it was to consider thoroughly the maximum lean principles to be respected for creating whole lean thinking (not only reduced scope of lean application). The leanness fitting (LF) contributes visually to analyse the evolution of lean practices to fit the lean principles. The more lean principles are covered by lean practices implemented the more exhaustiveness of Lean thinking is ensured to spread the relevant lean thinking and avoid retro actions to correct the missing or forgotten points. The outcomes are hopefully positive, propelling the lean thinking to continue its progress after the demonstrated benefits, which helps lean principles to expand to the logistics department.

### 5.9. Continuous improvement: expansion to the logistics department

Based on the interesting results obtained in the production line, the willingness to expand lean thinking emerged as continuous improvement. The logistics department has shown an interest in redesigning the actual transportation rounds owing to the lean principles. Indeed, weekly meetings were organized to fit the alignment of the actual operational actions with the strategic direction for cooperation and best practice exchange. The weekly coordination mechanism would hopefully be interested in extending lean thinking from the production department to other departments.

Implementing lean to transportation is rare. Among the fewest lean transportation findings, Sharma and Kodali (2012) have implemented lean concepts to avoid 60% of transportation waste by changing the layout of the truck parking area. Garza-Reyes et al. (2017) highlighted the interest of factory lean practices and considered them as important as the fuzzy algorithms and heuristics for transportation optimization. The first principle of lean is to define the value. The value for the transportation department is the *lowest rounds and the maximum truck fulfilment*. The delivery of shells to the customer is executed with an associated packaging 'loose per kit'. This packaging contains the necessary elements to fix the shell on the shipset, thus ensuring correct installation. The analysis in the logistics department revealed that empty spaces and partially loaded trucks are sent to the customer. Paying pointless logistic rounds and almost empty trucks under circulation in the current transportation is considered an NVA activity. Different financial data were gathered (Table 8) to calculate the transportation costs

**Table 8.** 'The actual transportation' versus 'the lean transportation' configuration.

Key elements	Evaluation of lean transportation	
	Transp. Config N°1 (actual situation)	Transp. Config N°2 (lean transportation)
Flyair contract	11 aircrafts 46 shells/aircraft	11 aircrafts 46 shells/aircraft
Palletizing dimensions	Common unit delivery (Loose per kit + shell) Global palletizing 135 × 210 × 130 cm	Dissociated delivery Adapted palletizing to shell: 122 × 112 × 130 Adapted palletizing to loose per kit: 135 × 210 × 130
Trucks capacity	13 m length, 2,25 m width, 200 cm height	
Transp. costs/delivery	Transp. Costs = Costs. Fuel + Costs. Driver + Costs. Structure 984.32 €	
Transp. costs (including margins and administrations)	Selling Price/Truck Delivery = Transp. Costs + 5% Admin. Costs + 6% Transp. Costs 1092.6 €	
Number of loaded pallets	9 Pallets/Truck	20 Pallets/Truck
Required trucks/aircraft	6 trucks : 5 containing 9 (shells + loose per kit) 1 truck containing remaining (shell + loose par kit)	3 trucks: 2 containing only shells (20 shells/Truck) 1 truck containing (6 shells + 4 loose par kit)
Transp. costs/flyair	72.112€	36.055 €
Financial savings	-	50%
Logistic configuration		

considering the actual configuration at (LogiPro Logistic provider of Aeroseat). The improvement suggests separating the deliveries of *the pallet of the shells* and *the pallet of 'the loose per kit'* to better fill the trucks. After receiving the product, the customer gathers both and proceeds to the installation. When studying the different sizes of potentially necessary packaging, the different costs and the different dispatching fulfilment of trucks (Table 8).

We may observe interesting financial savings with new lean transportation. The fulfilment rate increases from 9 pallets/truck to 20 pallets/truck, thus improving the filling rate. For the same Flyair order, six trucks were required: five trucks containing nine shells and nine loose per kit, and one additional truck containing only one shell and one loose per kit. In the lean transportation configuration, three trucks are sufficient. Two trucks contain only shells (20 shells) with an adapted new packaging, and one truck gathers six shells in their dimensional packaging and the required loose per kit for the all delivered shells. The lean transportation costs decreased by 50%.

## 6. Discussion and limitation

When a company in the aerospace industry targets lean conversion, the implementation of lean techniques should not be randomly practiced, an accurate methodology that considers the characteristics of the domain is required. The implementation methodology shows the usefulness of the following structured PTPC-AS/LF approach supported by a checking phase to match as closely as possible to the sectorial requirements and fit the maximum lean principles. This methodology involves a structured, contextual, and continuously improved approach to lead lean actions, lean management, and expand lean thinking. The contribution of the paper encompasses a structured qualitative approach

allowing to analyse the gradual lean implementation through PTPC-AS/LF steps. Aerospace characteristics, namely the market demand, the product complexity, the diversification, the safety and the supply-chain agility are introduced and argued to integrate the methodology. The aerospace correlations proposed and calculation of FLP 'Factor of Lean Practice' becomes significant useful index to priorities the Lean practices implementation tools matching the characteristics. A possibility to rank the lean practices implementation inside the step2 'T: Tools implementation' is interesting to counter the common random and self-sensitive approaches adopted by the manager and reminded in Table 2. The calculation of indicative qualitative FLP is a decision aided ranking. Each company of the sector leading a LP implementation can hopefully position the priority and increase the degree of matching the context. Moreover, the possibility to assign different weights to characteristics is a consistent aerospace matching to use by managers if necessary. The more lean-practices tools are contributing to tackling the aerospace specificity, the more index FLP increases revealing the priority to implement and adopt the tool. The leanness fitting is not only a summary, it becomes an important analysis in the step 'performance review', we claim that it is not enough to build operational performance but also to make the system undergoing lean conversion achieving lean maturity level. The leanness fitting is the possibility for managers to check gradually if they are responding to maximum of Lean principles. When lean principles are covered it means the leanness exhaustiveness and maturity level are increasing. If the covering leanness fitting is empty, it means the managerial teams are focussing efforts in one axis misleading other points. The careful 'leanness fitting' is analysis aspect that we suggest and argue to be useful for practitioners.

Also, this in-depth case study reveals the way the lean practices were implemented. The VM allowed a workstation

clarification with ergonomic consideration and visual warnings/ground paintings and digital work instructions that reinforces industry 4.0. The one-piece flow is the guarantee of a high-quality product assembled and treated one by one. The cellular layout allowed a regular and clear flow of the product assembly steps, avoiding cross flows, as well as wastes of motion and transportation. The standardized work instructions were useful in providing the workers with the correct steps and a common vision of the assembly steps. The TT and production leveraging allowed respecting the production cadence to honour the demand. Poka yoke seemed to be useful in sustaining the product quality, visually avoiding errors and accelerating the RFT rate. Regarding the setup times, there was a time saving of 43%. The detailed lean practices implementation complete the missing landscape of Lean practices in literature as particular contribution about the usefulness of Visual Management VM explained in the workstation (WS1) and the cellular manufacturing and its details along with the 11 steps of aerospace business set assemblies.

As found in the literature, the human aspect relating operators and management is of utmost importance jointly to consider with lean technics implementation. It contributes to the step 'Continuous improvement'. The top management is gradually becoming involved in creating a learning organization with operational worker skills. The place of workers within the problem-solving approaches has not yet been identified and adequately considered. Providing employees with training, resources, knowledge and authority to solve problems is crucial for the success of the lean initiative (Wang and Chen 2012). To support the involvement of the workers and to mitigate the resistance to change, a survey was conducted in Aeroseat along the three assembly lines to obtain the opinion of workers about 'lean management'. This step is useful to integrate into the step of 'continuous improvement' of the methodology. The questionnaire was anonymously completed to avoid any bias in the results. A total of 33 operators provided their opinions on a Likert scale (grading from 1 to 5) regarding six different points related to the lean approach. When asked about the '*involvement to the improvement with ideas*', the majority of operators (64%) answered that they are willing to contribute to improvements. Indeed, the experience and technical skills of operators make them confident in the product assembly. Among them, 42% are permanent contract agents (CDI), and 22% belong to temporary staff. However, only 12% of the CDI workers believed that their contributions could be *potentially approved by the top management*. This means that in the majority of cases, the workers are convinced of their non-consideration. A real effort in this direction should be made. The top management should develop and include more workers in their problem-solving approaches to create a *learning organization*. The consideration of employees is of utmost importance in succeeding as recognized in Panizzolo et al. (2012). Szulanski and Jensen (2006) conducted research to investigate the adaptation of workers to the previous original practices. The authors concluded that presumptive adaptation of knowledge could be detrimental to

performance. The top management has to display confidence, consideration and routines protocol to reinforce the commitment of workers.

The depicted case study revealed significant contributions to aerospace. The methodology is a combined approach linking PTPC (equivalent of PDCA) to AS/LF to create a contextualized generic, structured, chronological Lean practices implementation PTPC-AS/LF with the aim to be duplicable, transferable to other aerospace companies. The genericity of the approach constructs, with possibility to give the priorities to LP implementation, may also be tested and applied to other industries. If managers gaining consistent comprehension from the case would adapt it to their characteristics, our approach may gain in interest and be spread to wide-scale sectors and companies to extend the validity.

The beneficence of implementing lean and extension possibility observed in Aeroseat case through 'Lean logistics implementation' in 'continuous improvement' step comes to consolidate the spreading effect of successful implementation and the importance of lean thinking in the whole departments. Sustaining the lean development with different contributions offers a wide range of possibilities. Trying to extend the lean implementation thinking in aerospace specific field with its limitations is a constructive contribution that may inspire the aerospace lean literature landscape.

The future research axis would follow this contribution to commit in longitudinal study to extend the analysis of PTPC-AS/LF approach over time and to other case studies in the same sector to clarify the usefulness and the easiness of implementation to adapt and improve decision aided approach.

### 6.1. Limitation of the research

For each developed model, verification and validation are required. The usefulness of the lean implementation methodology was verified with one single Aeroseat case study because the model was implemented and stated as efficient results in terms of operational performances. We argue that both measures of quality and delay are the main important indicators to consider for Aeroseat, as stated by Drohomerecki et al. (2014), because reliability and quality are judged as significant in 74% and 70% of studied cases, followed by 59% regarding the delay and the speed of the flow. The limitation associated with the present study is the single case-study application. The transferability to other companies of the sector should be examined to generalize the implementation approach. Further studies should include other companies to analyse the global context of applicability to validate the interest of the model as a generalizable guideline. The suggested conceptual model may be highly dependent on the experience and judgements of the expert team. In the future, the validation of the developed model can also be performed quantitatively using other mathematical and formal models to test the quantified value of addressed characteristics.

## 7. Conclusion and perspectives

In a great number of research case studies (Table 1), the manner in which lean is implemented in companies of various industrial sectors has been analysed, disregarding the sectorial characteristics in general and the aerospace characteristics specifically. However, in the present research, we considered the *sectorial context* mentioned in (Jadhav et al. 2014) and included it in the analysis. The present authors would like to note that lean implementation slightly differs from one sector to another. The study case presented herein enables revealing how lean practices are implemented and how the sectorial context is considered during this phase of implementation. In the discussion section, it was revealed that aerospace characteristics were correlated with the choice of lean practices. The implementation model was built accordingly. Moreover, the study outstrips the scope of global manufacturing to demonstrate an application on disregarded aerospace sector with a deeper analysis of lean practices, including VM and the cellular layout (rarely considered in the literature). Although previously published research was mainly focussed on the benefits of lean implementation in manufacturing plants, our study acknowledges the importance of extending lean thinking to a different supply-chain part, such as logistics. The calculation of the transportation-cost saving reinforced the advantages of LP and lean logistics coordination to reduce the transportation waste. The case study, as a deep investigation of the implementation of lean practices in a specific sector, reveals its benefits and its limitations. It outlines a proof-of-concept for lean thinking deployment and expansion in the company. Lean implementation as demonstrated in this case study delivered promising results towards creating a 'lean system' instead of 'lean techniques' (Crute et al. 2003). In perspective, this is necessary to prove that the used methodology is likely to be replicated and adapted, serving as a guideline for practitioners in terms of inquiries and expectations, either in other aerospace companies or in other industrial domains. Scherrer-Rathje, Boyle, and Deflorin (2009) highlighted the initiative and support of the managers, appropriate training, appropriate selection of pilot projects and commitment of team members for successful implementation. Once the pilot project succeeds, it is significantly easier to develop lean as a learning system and optimized method. In this research, the benefits of lean implementation from the assembly line to logistics have been demonstrated.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

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**Appendix 1.** The link between lean practices LP and the aerospace characteristics to deduce the correlation

	Spec. 1 – market demand	Spec. 2 – diversification	Spec. 3 – complexity	Spec. 4 – quality	Spec. 5 – supply chain
LP.1: U cells	Quick assembly No motion time, no transfer time Possibility of produce more on the line Absorption of market demand possible Ideal case would be batch size production to absorb market demand Not correlated	Quick assembly and clear steps Easiness of changing references in U cells Diversification allowed One-piece flow sustains one reference production Easiness to switch to another reference to respect the diversification	Clear steps in a sequential way Possibility to split the complexity into different steps well designed in U cells Complexity monitored at steps Complexity of one piece is less difficult to manage than complexity of a batch To fit this specificity one-piece flow is positively correlated	In U cells no crossing flows Reduced risk of errors Possibility to check the quality at chosen steps Safety increase in defined steps One-piece flow is an enabler of quality control and automation Each step is subject to checking and verification piece by piece Quality increases with one-piece flow	Simplification of steps Sourcing products identified location Final product identified location Increase SC reactivity One-piece flow or batch size defines the quantity of production, no evident impact on supply chain. Not correlated
LP.2: One-piece flow	VM is internal enabler to increase the easiness and relevant access to information, tools and products. No obvious link to absorb the quantity of market is possible to state	VM is internal enabler to increase the easiness and relevant access to information and products. Possibility to deal with diversity of references becomes easier when VM is integrated and regulate the production flow SWI is the guarantee to accomplish the required tasks on time with less errors. Diversification of aeronautics can be sustained with many SWI to put in place to deal with variety of references	When complexity of product slowdown the process with increase risk of errors, the VM reduces the complexity, increase the accuracy and speed up the right assembly process (colour code, 5S, ground paintings) Complexity is linked to the number of pieces, technicality of pieces, critical assembly processes. SWI clarifies the steps of checking, assembly and the interactions with other specific steps as quality control. Positively correlated	VM clarifies the process, the tools and the procedures. The more accessible and resources are accessible easily the more the accuracy of assembly is sustained and quality supported	VM has two-fold impact on time and on quality. Reactive assembly is possible making the whole supply chain impacted by the quick assembly of each workshop in the floor from sourcing to delivering final products The supply chain reactivity is the result of each workshop reactivity highly supported by the SWI from raw materials receiving to final product deliveries
LP.3: standard work instructions	SWI is individual workstation improvement. Its link to improve the absorption of increasing market demand volume is not established	SWI is concerning the rhythm of production of some reference. Increasing or reducing the rhythm of production does not interfere in the possibility to face diversification of references. Not correlated	TT define the window of cycle time allowed regarding customer requirement in terms of quantity. Regarding this definition no link between TT and complexity can be deduced. Not correlated	Quality is obviously increased when the assembly process is not random but well announced with clarified steps and necessary checking tools, and assembly steps. Positively correlated	Supply chain reactivity is the possibility to deliver final customer managing all the steps from sourcing to deliveries. TT is regulating the flow along the production site and consequently along the supply chain. Positively correlated
LP.4: Takt time TT	Flow regulation with TT allows to respect on time the required demand with specific rhythm of production. The more TT is respected the more market demand can be absorbed	TT is concerning the rhythm of production of some reference. Increasing or reducing the rhythm of production does not interfere in the possibility to face diversification of references. Not correlated	TT define the window of cycle time allowed regarding customer requirement in terms of quantity. Regarding this definition no link between TT and complexity can be deduced. Not correlated	TT regulates the time of production. Basically, quality is increased if more time is allowed to inspection. TT is regulating the just necessary timing of assembly regarding customer requirements. If TT is too low the quality may be impacted. Implementing TT has no correlation with increase of quality	Supply chain reactivity is the possibility to deliver final customer managing all the steps from sourcing to deliveries. TT is regulating the flow along the production site and consequently along the supply chain. Positively correlated
LP.5: Poka Yoke	Poka yoke error-proofing is ingenious system to implement to avoid errors and products confusion. Implementing poka yoke in the best case everywhere is not a guarantee to be able to absorb market demand increase. No additional resource is ensured	Diversification is the possibility and the necessity in aeronautics to produce different references in the same workshop. The risk of confusing references is increased. Poka yoke becomes interesting approach to create defect-free flow and avoid confusing and mixture of orders	Complexity means technical, parts assembly and diversity of operations. Poka yoke if well designed avoid errors and reduce the complexity of assembly and the risk of fault assembly. Clarifications of the useful pieces with poka yoke may reduce the complexity of parts assembly and technical checking	Basically, the poka yoke was designed to exclude physically defective products to go through the process. The exclusion of defective parts ensures the quality rate increase	Poka yoke is mainly directed to the quality of product. No obvious link of implementing poka yoke and its impact on supply chain reactivity can be deduced

(continued)

Appendix 1. Continued.

	Spec. 1 – market demand	Spec. 2 – diversification	Spec. 3 – complexity	Spec. 4 – quality	Spec. 5 – supply chain
LP.7: SMED	<p>This practice has time-saving target to launch another production order.</p> <p>SMED sustains the absorption of market demand</p>	<p>SMED is basically designed to permit different reference production</p>	<p>SMED is related to the inter-times. No link of SMED to product complexity during the cycle time</p>	<p>SMED is related to the inter-times. No link of SMED to product quality during the cycle time</p>	<p>SMED related to time notion is an enabler for supply chain reactivity</p>
LP.8: Multiskills/Cross-training	<p>Multiskills make the staff inside the same workshops more reactive in case of disruptions. However, specific know-how at each workstation is required for the complex aeronautic products. No evidence with multiskilled staff to absorb more market demand, only possibility to react disruptions.</p> <p>Not correlated</p>	<p>Diversification requires different production lines or quick changeover time if the same production line. Anyway, increased training to cross-functions for the staff to increase the possibility to absorb different orders of different references</p>	<p>Multiskills provides elasticity to the production system. Each resource in the department is able to substitute another one. The more staff becomes multiskilled the more functions can be ensured and complexity is prevented from growing</p>	<p>Quality in aeronautics is an important fact and some managers may be sceptical to ensure multiskills afraid of losing quality level. For some fields like mechanics and electronics dedicated resources are preferred. Multiskills is not correlated with quality</p>	<p>Multiskills is related to time-saving because of possibility to substitute a resource by another trained one creates a reactive whole supply chain</p>