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Measuring lean implementation for maintenance service companies

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Stephan de Jong is currently a consultant at Deloitte, working in the field of Operations Excellence. He obtained his MSc degree in Aerospace Engineering, specialising in Aerospace Management and Organisation in 2012. At the time Stephan conducted the research at the MRO company he was also working there as Business Analyst. The work consisted out of data driven Lean Six Sigma improvement projects and management advisory and support. Afterwards he worked at TNO (Netherlands Organisation for Applied Scientific Research) as a Consultant/Researcher, focussing at among other topics Process Enhancement and Innovation, Operations Strategy, Operational Excellence, Demand Flow and Lean Manufacturing.

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Wouter Beelaerts van Blokland joint the Delft University of Technology, The Netherlands in 2004, to become lecturer on Value chain modeling and lean air transport systems within the chair Air transport and Operations (ATO) under direction of Prof. dr. ir. Santema. He successfully defended his PhD thesis on “Value-leverage by aerospace original equipment manufacturers” the 27th of October 2010 at Delft University of Technology in the Netherlands. He joined the faculty of Mechanical Engineering section Transport Engineering and Logistics under direction of Prof. dr. ir. G.Lodewijks in 2013 as Assistant Professor. He continued research on the development of methods to measure operations performance from a lean perspective involving production and service companies in general and in Aviation.

Abstract

Purpose – Implementation of lean manufacturing is currently performed in the production industry, however for the airline maintenance service industry it is still in its infancy. Indicators such as work in process, cycle time, on time performance and inventory are useful indicators to measure lean implementation, however a financial economic perspective taking fixed assets in consideration is still missing. Hence the purpose of this paper is to propose a method to measure lean implementation from a fixed asset perspective for this type of industry. With the indicators, continuous improvement scenarios are explored by value stream discrete event simulation.

Design/Methodology/ Approach – From literature indicators regarding asset specificity to measure lean implementation are found. These indicators are analysed by a linear least square method to know if variables are interrelated to form a preliminary model. The indicators are tested by value stream based discrete event simulation regarding continuous improvement scenarios.

Findings – With the new found Lean Transaction Cost Efficiency Indicators; turnover, gross margin and inventory per fixed asset, T/FA, GM/FA and I/FA, it is possible to measure operations performance from an asset specificity perspective under influence of lean implementation. Secondly, the results of implementing continuous improvement scenarios are measured with the new indicators by a discrete event simulation.

Research limitations/ implications - This research is limited to the airline MRO service industry regarding component repair. Further research is necessary to test the indicators regarding other airline MRO service companies and other sectors of complex service industries like health care.

Practical implication - The Lean Transaction Cost Efficiency Model provides the capability for a maintenance service company to simulate the effects of process improvements on operations performance for service based companies prior to implementation.

Social implication - Simulation of a Greenfield process can involve employees with possible changes in processes. This approach supports the adoption of anticipated changes.

Originality/value - The found indicators form a preliminary model, which contributes to the usage and linkage of theories on lean manufacturing and transaction cost theory – asset specificity.

Keywords lean implementation, fixed asset, transaction cost, simulation, aviation, MRO

Paper type Research paper

Introduction

The aviation industry is characterized by a highly dynamic and volatile business environment (Doganis, 2002; Doganis, 2001). Competition between airlines is intensifying and margins are decreasing (Schmidberger, Bals, Hartmann and Jahns, 2008) under influence of "low cost" airlines and the rapid deployment of airlines in the Middle East. This development created a necessity to innovate and improve aircraft Maintenance Repair and Overhaul (MRO) service operations by implementing principles of lean manufacturing (Womack and Jones, 2005; Murman *et al*. 2002).

The MRO service company under research (Chün, 2009) experienced lean implementation and provides services to the airline industry such as Air France-KLM for repair of auxiliary power units and air cycle machines. The company was started in the year 2000 as a Joint Venture between Hamilton Sundstrand and KLM Royal Dutch Airlines. Due to changes in the maintenance repair and overhaul market the company changed ownership. KLM became the full owner and appointed a new management in 2006 because the service level measured by on time performance of the serviced products was 35% and the average turnaround time was 28 days, while 15 days was promised to the customer. To stay in competition it was necessary to improve the on time performance and turnaround time of the serviced product to increase the service level. Aircraft types involved are from Boeing and Airbus. The serviceable systems of these aircraft are Auxiliary Power Units (APUs) and Air Cycle Machines (ACMs).

Preliminary research on the implementation of Lean Six Sigma (Beelaerts van Blokland *et al.* 2008a) with the SME company under research showed an improvement of the turnaround time for pneumatic components first from 28 days to 20.49 followed by a further improvement to 13.13 days. Given the significant improvement on turnaround time of the serviced product, the management team of the company continued the "Lean Six Sigma" approach. A need for measuring lean implementation during the sustainment phase was expressed.

Maintenance Repair and Overhaul services (MRO) can be defined as, all actions which have the objective of retaining or restoring an item during its lifecycle in which it can perform its required function. The actions include the combination of all technical and corresponding administrative (certification, regulation, registration) managerial and supervision actions (European Federation of National Maintenance Societies vzw, 2011). By this definition the MRO industry can be characterized by its high asset specificity due to airline – aircraft related regulation and certification of processes, assets and components for reasons of safety. The assets to be used for MRO services can only be used exclusively for this type of service and worthless in any other type of industries (Arnold, 2000). Asset specificity belongs to the theory regarding transaction cost economics (TCE) of Williamson (1981) and introduces the financial economic and transaction perspective. Current research towards lean implementation in the MRO service industry does not provide indicators covering this financial economic perspective. By having these indicators it would be possible to measure operation performance from an asset specificity perspective under influence of lean implementation. The other aspect regarding transaction cost economics are transactions. Transactions are necessary elements for a value system to generate value. As transactions takes randomly place, these can be used to test performance indicators by discrete event simulation.

This paper continues with a literature review to identify the indicators. A linear least square methodology is used to know if the indicators can form a preliminary model. Data analysis is performed to measure operations performance through time under influence of lean implementation.

The final part of this paper is to test indicators by a value stream mapping based discrete event simulation. By simulation of continuous improvement scenarios the company can prepare for strategic decisions regarding the use of assets and resources.

Literature review

From the introduction it surfaced that asset specificity characterizes maintenance repair and overhaul processes which need to be researched in more detail. The other aspect is lean implementation. The company changed management and started the implementation in 2007. Literature research is necessary to identify variables to measure lean implementation.

Transaction Cost Economics (TCE) – Asset Specificity

Williamson (1979) proposed the theory on Transaction Cost Economics (TCE) by the publication "Transaction cost economics: the governance of contractual relations" in the Journal of Law and Economics. TCE lies at the intersection of three fields of research, namely: economics, law, and organisational theory and defined as "a transaction occurs when a good or service is transferred across a technologically separable interface" (Williamson, 1981) with focus on external transactions. Williamson, (1985) positioned asset specificity as the most critical dimension alongside opportunism and bounded rationality as the three main principles of transaction cost theory TCE.

The TCE has been used in the Aerospace MRO industry by Masten (1984). Masten looked at aerospace procurement, using a measure of the degree to which components used in production were adaptable for use by other firms. The research found support for the probability that a component procured internally increases with the complexity of the component being procured. Masten's research was preceded by related studies of Monteverde and Teece (1982a) (1982b), they referred to asset specificity and vertical integration versus supplier switching cost in the car industry, indicating there is a relation between complexity of the company and transaction costs.

Douglas (1999) stated there is more to transaction costs than just putting a "T" in a cost function, in line with earlier reviews on the TCE by Shelanski and Klein (1995). Williamson mentions three limitations of his work; its crude form, instrumentalism and incompleteness (Williamson, 1998). As mentioned asset specificity is the most critical dimension of TCE. Goods and services with high asset specificity cannot be used in other transactions beyond the field of expertise without huge additional costs (Arnold, 2000). Low asset specificity means that little information has to be exchanged with the transaction partner. High specificity is related to complex information for complex products, processes and services dominated by extensive regulations and certification by airline authorities for safety reasons.

TCE needs to find actual indicators with predictive powers (Arora, 2007) and transactions should be organized (Hardt, 2009) to assess these. This research paper follows on this argument of addressing indicators related to company internal transactions focusing on asset specificity instead of external transactions. Like with external transactions, internal transactions are taking place as components are transferred internally across technologically separable interfaces in combination with complex processes and information between interfaces. Figure 1 shows the framework as by Canbäck (1998) which is adapted to indicate how TCE will be used for this research with focus on internal transactions within the company. This framework was further developed by Canbäck *et al.*(2006) for assessing company performance relative to size. The three main principles of TCE are opportunism, bounded rationality and asset specificity. Uncertainty and frequency however are still considered alongside the main dimensions. Furthermore, production costs complement the transaction costs, since multiple sources state that transaction cost should not be seen as a stand-alone: the total costs of a system need to be minimised. Bounded rationality and opportunism are not playing a role in this research. The motivation is that bounded rationality refers to individual behaviour for instance by customers which is intendedly rational, but only limited (Williamson, 1985). In this market of aircraft maintenance service it is about long term contracts based upon

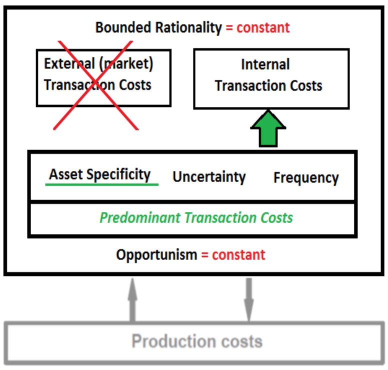

Figure 1. TCT preliminary framework, adapted from Canbäck (1998).

fixed agreed pricing. As it is an oligopolistic market the opportunity to switch to other service suppliers is limited, therefore opportunism is considered to be a constant.

Asset specificity in MRO processes is present in site specificity, test cells, building and special tooling, which are all directly related to the products and the requirements on quality and safety by the airline industry. In order to provide for an empirical measurement the book value of the company's fixed assets is taken as a proxy for the asset specificity. The total Fixed Assets (F/A) will be used further in this research and consist of:

- Buildings; consists of the building itself and investments and alterations to it.
- Machinery and equipment; special tooling, test equipment, specific maintenance equipment calibrated and certified for aerospace.
- Component exchange pool; assets of the company involved in an exchange pool of spare parts necessary to reduce the risk of "aircraft on ground" which is the case when an aircraft cannot be utilized due to unavailability of parts / components.
- Under construction; any of the other four items being prepaid or actually under construction.

Furthermore, fixed assets are known as variable in relation with the financial structure of the firm. Hall *et al.* (2000) reported about the relation between long and short term debt, asset structure, size, age of company and profitability for SME's in the UK. The effect of growth on short-term debt, however, was consistent across industries whilst profitability had no effect on long-term borrowing in any industry. Jaggi *et al.* (2001) concluded that revaluations of fixed assets are positively associated with the firms' future operating performance, suggesting that the managers' motivation for revaluation of fixed assets has been to signal fair value of assets to financial statements users. Jacobs *et al.* (2011) modeled the relation between product portfolio complexity by the multiplicity, diversity and interrelatedness of products within the portfolio and the impact on operational performance. The model explicitly addresses the roles of organizational learning and the character of fixed assets (utilization and flexibility). From this reasoning organisational learning by means of lean implementation and continuous improvement is related with utilisation and flexibility of the fixed assets. The fixed assets appear to be an important variable in relation to operations performance and lean implementation.

Lean and Six Sigma

The Lean philosophy (Womack, Jones, Roos, 1990) and (Womack and Jones, 2003, 2005) is well established in the car manufacturing industry. Murman *et al.* (2002) researched lean manufacturing in the aerospace industry and described lean as follows: "Becoming lean is a process of eliminating waste with the goal of creating value."

Six Sigma originates from the mid-1980, when the engineers in Motorola Inc. in the USA were inspired by quality improvement methodologies like Quality Control and Total Quality Management. George (2002) introduced the combination of Lean and Six Sigma. The goals of Lean Six Sigma are to maximize performance by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed and flexibility. Value stream mapping introduced by Rother and Shook (2003) and Hines (1998) allows for a clear visualization of design activities' characteristics and interdependencies, the in-between inventory or transport data and the overall planning requirements and static throughput data. They introduced the takt-time of the process to relate actual customer demand with capacity. According Cutcher-Gershenfeld (2004) the following effects of lean implementation can be expected. Elimination of defects, reduction of production- and development costs, reduction of cycle time and inventory levels, increase profit margin and improve customer satisfaction.

Lean implementation in the aviation service industry

In the airline industry the so called low cost carriers like Ryanair and EasyJet are competing on turnaround times and punctuality or on time performance to increase the operations performance of the aircraft. Research by Beelaerts van Blokland *et al.* (2008b) regarding turnaround processes of aircraft at the airport showed how KLM could improve the turnaround time for the Boeing 737-800 with 42% by lean implementation through reduction of waiting times in "above the wing" processes. The turnaround times of a KLM aircraft was about twice as long compared to a Ryanair aircraft in 2007. A short turnaround time has a positive effect on the utilisation rate of the aircraft as fixed asset and as such turnover and profit. This example in the service industry shows the relation between the turnaround time, on time performance and fixed assets from a lean implementation perspective. In maintenance service the cycle time (Cutcher-Gershenfeld, 2004) or turnaround time (TAT) indicates the level of efficiency regarding the use of fixed assets. The indicator on-time performance (OTP) reflects the effective use of the assets.

From this research towards the maintenance service industry cycle times or turnaround times, on time performance, the use of inventory and fixed assets appear to have a relation with operations performance under influence of lean implementation.

Lean implementation in the industry

Research towards lean implementation for SME's in the UK was reported by Achanga *et al.*(2006). They identified leadership, management, finance, organisational culture and skills and expertise as the most pertinent issues for the successful adoption of lean manufacturing for SME's. Scherrer-Rathje (2008) researched the implementation of lean in the food processing industry with mixed results. One implementation was positive and the other was negative. It seems that just implementing lean is not a guarantee for success. The bottom-up approach was not successful as there was a lack of leadership and management commitment. After the commitment was established the lean implementation became successful. Culture and discipline as devised by Mann (2010) are an essential aspect on how to create a lean culture. To sustain lean implementation the entire company needs to be involved following the basic elements of lean thinking and to implement a process of continuous improvement to reduce defects, improve customer demand and better utilise the assets and recourses.

Bhasin (2011) and Singh *et al.* (2010) reported about lean implementation for production companies however the cost benefit or financial aspects are still missing. Lu *et al.*(2011) remarked the difficulty to compare future value chain structures on effectiveness indicating it would be of interest to have methods and tools to test these future value chain structures. Jeong and Phillips (2011) addressed the possibility for further research on the combination of value stream mapping with discrete event simulation to predict effectiveness of the improvement. Singh *et al*. (2012) referred to value stream mapping methodology for lean implementation in a production environment. Significant performance improvements were observed. It was found that reduction in lead time was 83.14 percent, reduction in processing time was 12.62 percent, reduction in work-in-process inventory was 89.47 percent, and reduction in manpower requirement was 30 percent. The rise in productivity per operator was 42.86 percent.

Further research was advised to incorporate a cost benefit analysis as the financial perspective was still missing. Research by Beelaerts van Blokland *et al.* (2012) presented indicators to measure value leverage and stability of aerospace companies. The variables turnover (T), R&D and profit with the employee numbers as denominator were found to be related to form a model expressing the leverage and stability of value flow of a company. The variable T/E, RD/E and P/E form the value leverage model.

To summarise, researchers advised future research towards the cost-benefit or financial aspects of lean implementation. Lean implementation as an organisational and cultural aspect was linked with performance regarding fixed assets. It seems lean implementation may have an impact on the utilisation of fixed assets. Similarities are found between aircraft turn around and preliminary research towards maintenance service processes (Beelaerts van Blokland *et al.* 2008a). For airlines the link between operations performance and fixed assets is clearly demonstrated by performance regarding ATAT and OTP of aircraft. For both types of services the importance of turnaround time and on time performance can be recognized.

This research will explore the combination of value stream mapping and discrete event simulation as various researchers mentioned it would be helpful to have these methods and tools for design of processes from a lean perspective.

From literature the main research question is formulated as follows; how to measure operations performance from an asset specificity perspective under influence of lean implementation regarding cycle time and on time performance for maintenance service companies in the aviaton industry. The following sub questions are proposed:

- can the year of lean implementation regarding turnaround time and on time performance be identified?
- what indicators capture lean implementation for maintenance service companies from an asset specificity perspective and can these indicators form a model?
- what are the operations performance boundaries under influence of further continuous improvement scenarios?

Preliminary framework
From literature the following indicators are found with the goal to measure operations performance from an asset specificity perspective under influence of lean implementation regarding cycle times and on time performance for maintenance service providers. The new found indicators are:

- *Fixed assets (FA)*
  The transaction cost economics – asset specificity perspective (Williamson, 1985) introduce fixed assets (FA) as a variable which can be used for the denominator of the variables.
- *The Gross Margin per fixed asset(GM/FA)*
  This variable measures the benefit in relation to the fixed asset resulting in the indicator; GM/FA. Jaggi *et al.* (2001) and Jacobs *et al.(*2011) referred to the relation between operations performance, utilisation, flexibility, organisational learning and fixed assets. Sigh *et al.* (2012) referred to the cost benefit in the context of lean implementation.
- *Inventory per fixed asset (I/FA)*
  Inventory is in maintenance service processes crucial to enable servicing of equipment and relevant to the principles of lean manufacturing according Womack and Jones (2003), George (2002) and Cutcher-Gershenfeld (2004). Inventory is an essential value driver for the maintenance process and related to the fixed assets. From this reasoning the indicator I/FA measures the variable inventory in relation to the fixed assets.
- *Turnover per fixed asset (T/FA)*
  Continuous flow suggests the flow of products through the system. To measure the flow of value through the system the turnover (T) measures the flow of products through the processes from an operation performance and financial economic perspective (Beelaerts van Blokland *et al.*(2012). The turnover per fixed asset measures the flow in relation to the fixed assets (T/FA).

The variables Turnover per unit of Fixed Asset (T/FA), Gross Margin per unit of Fixed Asset (GM/FA), Inventory per unit of Fixed Asset (I/FA) will be used for analysis on lean implementation. These new indicators complement the indicators; turnaround time (ATAT) and on time performance (OTP).

Method

The method comprises the data sources, statistics, value stream mapping, discrete event simulation and the levels of detail based upon the organization structure in the company.

Data sources
The analysis is based on data available from annual reports and data from the companies database ERP system. The data consists of the shipped APUs, the shipped line replaceable units (LRU's), and the shipped pneumatic components. The ERP data dates back to 01-04-2006 spanning a period of five years. The Lean implementation of the company under research started in 2007. The years before 2007 will be used as pre-Lean years. The years 2007-2011 will be used as post-Lean years. The annual reports date back to the year 2001. The data concerns the valuation of the fixed assets per year including depreciation based upon accountancy standards applicable to the company. Depreciation and investments takes place every year however stable over time. The data are covering 11 years. For confidentiality reasons, values presented in graphs in the analysis and simulation are indexed with respect to the year 2007. Other data sources were; manufacturers' manuals and the VSM sessions and inquiries. Financial data are of confidential nature. By indexing the data the authors were allowed to use the financial data. The year the lean implementation started, 2007, is taken as reference year. The research was closed in 2012 therefore the population covers 11 years with 11 data points per variable.

Statistical analysis

A linear regression analysis is applied to know whether the indicators are statistically significant and if these have inter-relations through time to form a preliminary model. To analyse the processes Value Stream Mapping by Rother and Shook (2003) and (Hines, 1998) is used in combination with statistics for making probability plots (Allen, 2010). These methods are useful to depict all the process steps and transactions related to cycle time and asset specificity like inventory and machinery.

Value Stream Mapping (VSM) and discrete event simulation

A simulation model of a system enhances the VSM model in multiple ways (Marvel and Standridge, 2009), (El-Haik and Al-Aomar, 2006). Both structural and random variability are commonly included in simulation models and the effects of variability on system performance can be determined. Discrete event simulation (Basem and Raid, 2006) is used to explore the effects of continuous improvement scenarios. Design for Six Sigma solutions and lean production (Houshmand and Jamshidnezhad, 2006) can be studied before piloting or modification and as such risks can be better managed by preventing defects and reducing cost that already emerge from the simulation model.

Agyapong-Kodua *et al.*(2009) apply system dynamics and discrete event simulation as tools to achieve a dynamic value stream model. These authors define a dynamic model as a model that incorporates interdependencies and interactions between variables to estimate system performance of future state value streams. They explained that a system dynamics model based on causal loops and consequent differential equations distinguishes cause-effect relations, and as such results in a set of potential change parameters. Discrete event systems are dynamic systems that evolve in time by the occurrence of events and transactions at possibly irregular time intervals (Dotoli *et al.* 2012). Transactions like work orders can randomly brought in to the system to simulate the performance of the system. The factors frequency and uncertainty are represented in this research by means of the number of work orders (WOs) handled, the number of tasks performed and the kind of work scope of a WO reflecting transactions. Kelton *et al.* (2010) stated that from a practical viewpoint, simulation is the process of designing and creating a computerised model of a real process or proposed system for the purpose of conducting numerical experiments to give a better understanding of the behaviour of that system for a given set of conditions. It helps to define systems, to identify all relevant processes, as well as to quantify these processes, to investigate transactions and to validate possible future state systems and a powerful tool for Lean Six Sigma experts

Levels of analysis

With the analysis it is important to consider the larger processes as well as the processes that are necessary to execute single transactions. According to Horváth and Möller (2004), this could result in problematic interdependencies whenever the execution of processes of one level influences the other level. In line with this argumentation the company under review has been divided into appropriate levels for closer investigation. The research considers the following levels: 1) Company, 2) Department, 3) Process, 4) Transactions. Figure 2 shows the respective levels. The product department, handling the ACM's represent Level 2. ACM's have an own dedicated work area separated from the other products. As such, 1 specific ACM process represents Level 3 and the transactions of that process are Level 4.

- *Level 1; company*. The company has been divided into two major product categories, being the Auxiliary Power Units (1a) and the Pneumatic Components (1b).
- *Level 2; Air Cycle Machine (ACM).*The ACM product category, has been chosen to represent level 2 of the analysis. The data of this level has been collected and calculated from the Quantum ERP database. The ACM product category, in turn, consists out of multiple types of ACMs; they are indicated with the type of aircraft they are deployed in.
- *Level 3; aircraft type Boeing 747 ACM*. Aircraft type has been chosen to represent the third level of the firm. This level entails one specific product and the associated processes. The Boeing 747 ACM has been chosen, since it is the ACM with the highest number of WO's at the ACM Island throughout the period between 01/04/2006 and 31/12/2011. Most of the other ACMs have too little work orders to enable for the intended analysis. The B747 ACM is also responsible for the largest part of the value flow through the ACM Island, making it the most suitable candidate for analysis.
- *Level 4; transactions.* This level concerns the actual transactions of a specific product related assembly process. In this level the changes and improvements regarding the processes have to be implemented. The last step of this research is to run scenarios by discrete event simulations to know the effect of proposed changes and improvements.

Analysis

This section presents the data analysis regarding company level 1. The known and new found indicators in literature are analysed to know if the new found indicators can form a preliminary model to measure operations performances from an asset specificity perspective under influence of lean implementation.

Value stream analysis and analysis by known indicators

By a value stream analysis (VSM) in 2007 a future state was designed. The process was changed as follows.

- A pre-test of the components as first and primary process step was introduced when the machines arrived at the company, instead of putting the machines in stock.
- From this process step spare parts could be ordered with suppliers earlier in the process.
- Disassembly and assembly were reorganised as one integrated process instead of a separate

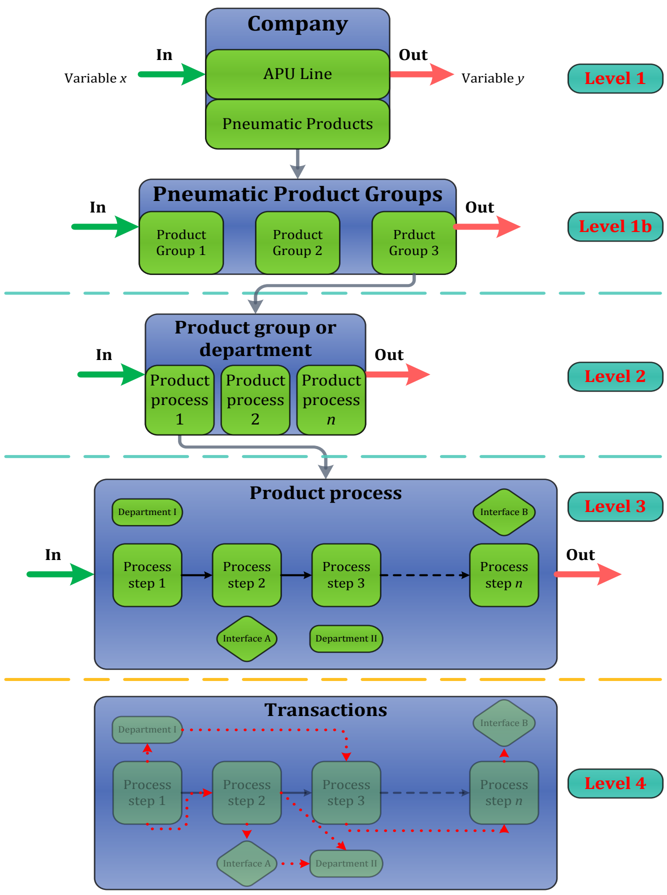

Figure 2. Company Levels to investigate.

processes. The mechanics performed both tasks.

- Mechanics, certified for quality control performed their task in the assembly process instead in a separate process.
- A pull mechanism was introduced reducing waiting times and the number of components in the process.

The result of this lean implementation was the reduction of the ATAT from average 28 days to 20.49 days in May and 17.62 days in June and further decreased to 13.13 days in July 2007, as reported by Beelaerts van Blokland *et al.*(2008b). From the graphs (figure 3) it can be noticed the average turnaround times improved from average 28 days to around 13 days, which is an improvement of more than100%. The on time performance increased from 35% in 2006 up to 80% in 2008, which is an improvement of over 100%.

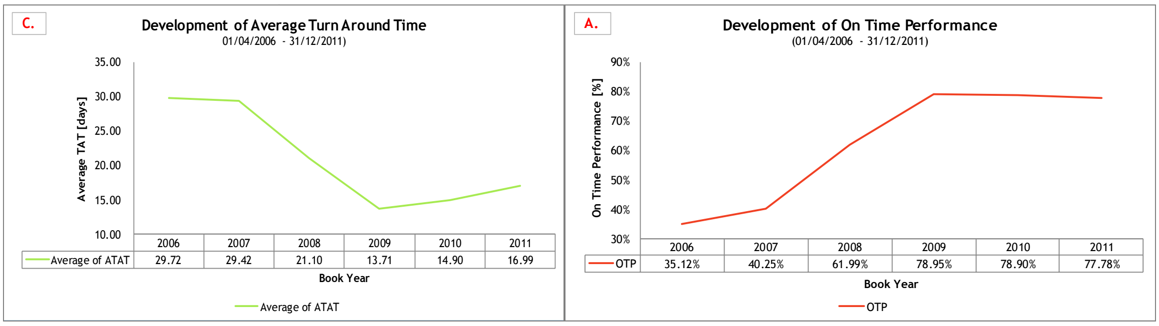

Figure 3: Turnaround (ATAT) time and On Time Performance (OTP) in years 2006-2011

To answer the first sub research question; can the year of lean implementation regarding turnaround time and on time performance be identified? Both indicators ATAT and OTP show a change in performance starting in 2007, the year of implementing lean. The improvement continues up to 2009. From 2009 up to 2011 there is a stabilization. From the graphs it can be concluded that lean implementation started its influence indeed in 2007.

Analysis with new indicators

To know if the new found indicators (section 2.5) turnover per fixed asset (T/FA), inventory per fixed asset (I/FA) and the gross margin per fixed asset (GM/FA) can be used for measurement, first a linear least square analysis is applied to prove if the indicators are statistical significant. The statistical significance for linear trends is tested through a two-tailed test at a level of significance provided in the tables (Allen, 2010). A level of significance between 0.05-0.1 is accepted as boundary for statistical significance. The calculated R-value is tested against the given significance level by comparing with the corresponding critical value. The actual *p* value is calculated and presented in the last column (Table 1), the number of observations N is given in the second column, the level of significance is positive, however the number of observations are limited as the sample set concerns yearly reporting by one company.

Table 1. Level 1 - Statistical significance for the indicators over time.

Level	N	Indicators	R^2-value	R-value	Significance Level	Critical Value	Significant	Actual p
1.	11	T/FA	0.9454	0.9723	0.001	0.847	Yes	0.00000
1.	11	GM/FA	0.7661	0.8753	0.001	0.847	Yes	0.00042
1.	11	I/FA	0.7686	0.8767	0.001	0.847	Yes	0.00040

Analysis of the indicators over time (2001-2011) on company level resulted in the graphs provided in figure 4. The indicator turnover per unit of fixed asset (*T/FA*) increases from 2001 to 2011 with 433%. The company also shows a nearly quadrupling of the performance on the gross margin per unit of fixed asset (*GM/FA*).

Regarding the model residuals, the years 2004, 2005 and 2006 show outliers regarding GM/FA. The gross margin was unstable and weak in these years. The reason for this can be found in the low service level of 35%, long turnaround time of the serviced products of 28 days as stated in section one and figure 3. In 2006 the company decided to change the management and start lean implementation. In

figure 4 the graph shows the weak performance regarding GM/FA in the years before 2007. The new appointed management started implementing lean in 2007. From 2006-2007 the GM improves and becomes more stable from 2008. For the indicator inventory per unit of fixed assets (*I/FA*) the performance increases from 2001 to 2011 with 177%.
The pattern shows a steady increase which can be explained by the effect of a reduction of the ATAT and increase of work orders (WO), which makes it possible to gradually increase turnover using the same fixed assets. Depreciation and investments took place every year however stable over time. There were no significant investments in fixed assets or employees which could have influenced the operation performance otherwise than process improvement. Development and significance of the indicators through time, complement with the data presented in Table 1.

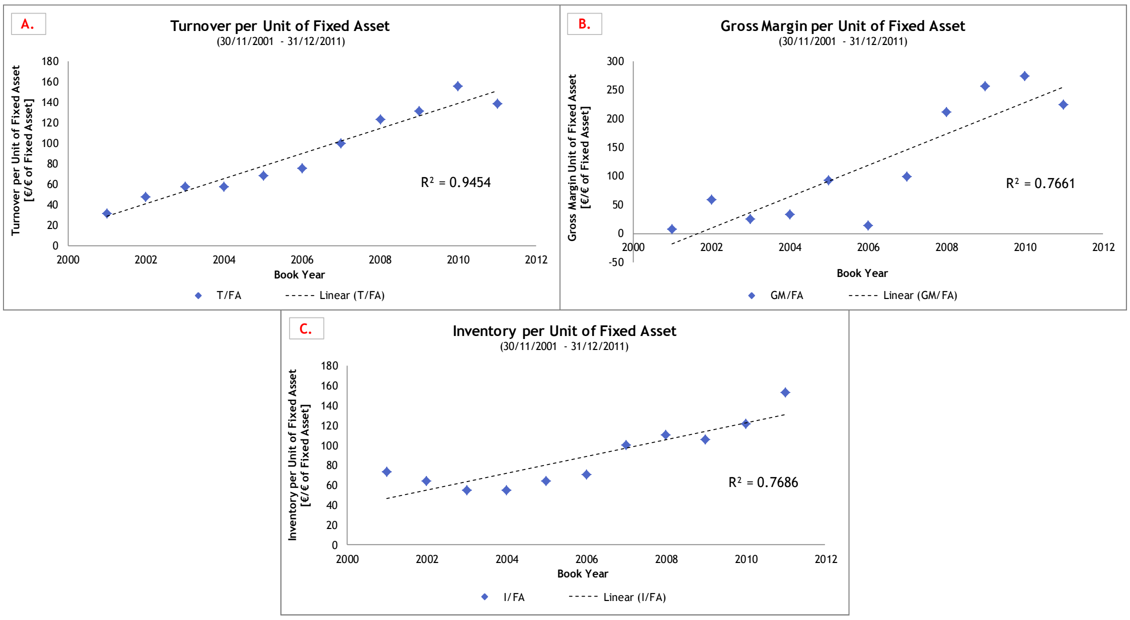

Figure 4. Development and significance of the indicators through time.
A.) *T/*FA. B.) *GM/*FA. C.) *I/FA*. [Values indexed with respect to 2007]

To further analyse the operations performance from an asset specificity perspective under influence of lean implementation, the questions was raised if these indicators have interrelations.

Analysis of relations between indicators
The relations between indicators T/FA, I/FA and GM/FA are exposed to a statistical analysis. Table 2 presents the data concerning the significance of the relations between indicators to a linear regression line. The relations between variables show to be significant as these are within the critical value.

Table 2. Level 1 - Statistical significance relations between the indicators

Level	N	Indicators	R2-value
1.	11	T/FA vs. GM/FA	0.8867
1.	11	T/FA vs. I/FA	0.7703
1.	11	GM/FA vs. I/FA	0.711

The next step is to know how the data spread over time regarding shape, direction and relative position which is presented in the next section.

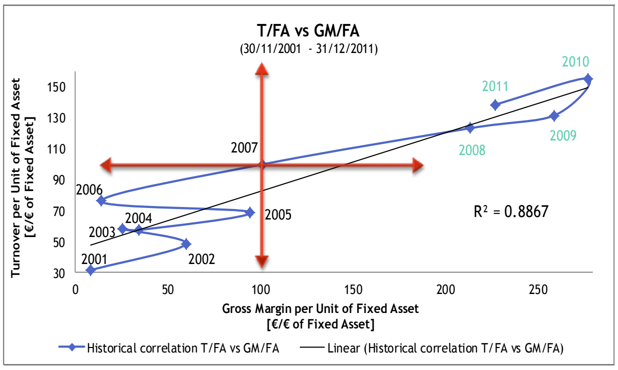

Figure 5. Level 1 - T/FA vs. GM/FA with clustering and quadrants visualisation. [Values indexed with respect to 2007]

Measurement with the new indicators.
Figure 5, presents the development of the relation between *T/FA* vs. *GM/FA.*

The relation between indicators T/FA and I/FA in figure 6 shows a similar pattern. The relationships between the indicators are still developing and not stable yet. Main difference is the large increase in 2011 for *I/FA* with respect to the previous years. When relating the indicator *I/FA* and *T/FA*, an increasing operations performance on the inventory per unit of fixed asset is measured. In figure 5 and 6 it can be observed that the performances are located in the lower left part of the graph for the year's 2001-2006 compared to the performances for the years 2008-2011, which are located in the upper left area of the graph. The year 2007 in the middle marks the start of lean implementation and show a first improvement compared to 2006. The years in the lower left part can be marked as "pre lean", the years

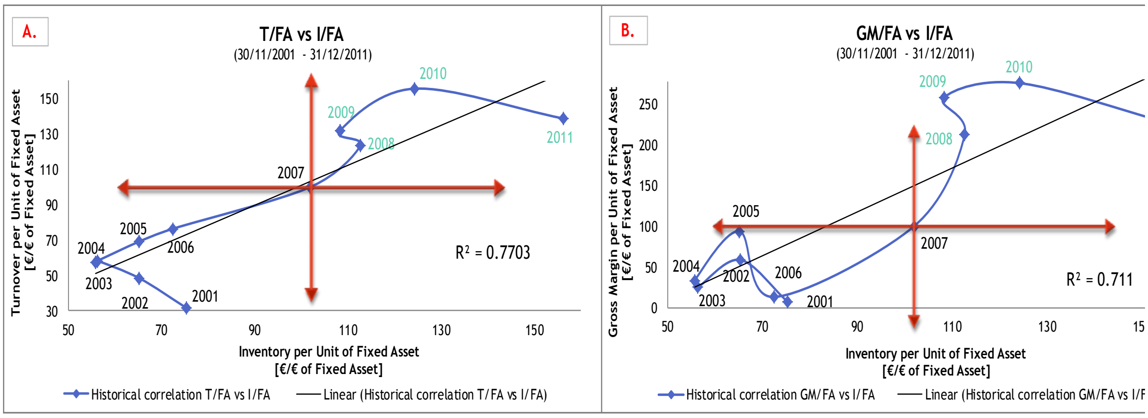

Figure 6. Level 1 - Quadrants visualisation in graphs A.) T/FA vs. I/FA B.) GM/FA vs. I/FA [Values indexed with respect to 2007]

in the upper right part can be marked as "after lean". Interestingly, for all the graphs in figure 4 and 5 the performance increased over time, however for the graphs in figure 5 and 6, a remarkable improvement is visible. The measured performance improvement with the new indicators corresponds with the lean implementation measured by the indicators ATAT and OTP.

Preliminary model composed by indicators; T/FA, GM/FA and I/FA.
The indicators show to have relation over time (2001-2011). From figure 5 and 6 it can be observed that the operations performance, measured with the new indicators T/FA, GM/FA and I/FA, can be orientated in the phase before lean implementation in the left under part of the graphs. After implementing lean in 2007 the indicators measure performance increase which is positioned in the upper right side of the graph.

The remarkable improvement is measured with the new indicators and is supported by measurement with the known indicators ATAT and OTP. The OTP improved from 35% to 77% from 2007 up to 2011. The Average ATAT was halved, the decrease started as of 2007. As these indicators ATAT and OTP refer to lean implementation by George (2002) and Cutcher-Gershenfeld (2004) it can be reasoned that the operations performance improved under influence of lean implementation regarding turnaround time and on-time performance. In the discussion part the influence of endogenous and exogenous factors are reviewed.

With the preliminary model the second sub research question can be answered; what indicators capture lean implementation for maintenance service companies and can these indicators for a model? The answer is that the new found indicators T/FA, I/FA and GM/FA can form a model as these show an interrelation. With the indicators it was possible to measure operation performance from an asset specificity perspective under influence of lean implementation regarding cycle time and on time performance. The results are supported by measurement with the known variables ATAT and OTP, and the moment lean implementation was actually implemented.

Simulation

The simulation is introduced as several authors referred to the combination of value stream mapping and discrete event simulation to explore results of improvement scenarios prior to implementation. For this research the preliminary model is tested by exposing the value system to several improvement scenarios. The simulation is focusses on level 4, transaction level (figure 2). This level concerns the actual transactions of a specific product related assembly process. In this level the changes and improvements regarding the processes have to be implemented. The first step is the baseline simulation, the second step is to run scenarios by discrete event simulations to know the effect of proposed changes and improvements.

Baseline simulation

The simulation starts at the first step, logistics, where ACMs come in together with other pneumatic components. In the second step the ACMs wait at a receiving area until their WO is created and the routing for a specific work scope is known. Within the third step five existing types of ACMs are routed to “Other ACM processes”, where they are processed through 6 process steps. When ready the ACMs are routed to logistics again, where specific statistics are gathered, and they are shipped when a shuttle leaves. Another step shared by multiple products is CAR (Customer Account Representatives), where various hold-ups and accompanying processing is simulated. Last shared modelling block is the WO creation block, where WOs and some entity specifics are assigned. The fictive new ACM is simulated in detail with four work scopes: 1) Repair (spinning condition), 2) Overhaul (seized condition), 3) Test only and 4) Return As Is. A fifth classification could occur during the simulation, when repair of a certain unit is not economical anymore.

The base line simulation results have been validated by comparison with historical data and by consultation of a process expert. One simulation run entails 100 replications of 365 days each, this provides with accurate averages and half width values. The half width value provides with the range within which 95% of the measurements averages fall and is a standard output of the used Arena software.

Changes for improvement, transactional level 4

With the base line simulation in place, four changes of improvement on the Level 4 (transactional level) are proposed. The model is rebuilt accordingly into the final model, the changes of improvement are derived from the principles of lean manufacturing:

- *Levelling schedules between various departments*
  Working hours between departments are harmonised, at least one person should be present at every department at the start of the working day. A continuous check whether there are parts in need of Non-destructive test inspection is part of this category, in the base simulation this is only checked twice a day. Reconciling working hours could prevent some specific hold-ups. Theoretically, the higher the incoming flow of new ACMs, the higher the benefit of levelled schedules should be.
- *Inventory*
  The second improvement entails shorter lead times for parts ordering, through negotiation, cooperation, and a higher level of supplier involvement, thereby allowing for lower inventory levels. Some other small delays in parts ordering are taken out as well with this change.
- *Introducing additional transactions*
  The third Level 4 alteration concerns the internal introduction of a necessary repair; this is however only an example of probably many possible extra internal transactions. Purpose is to show that the number of transactions not necessarily needs to be minimised for better overall system performance or lower total cost. Recall that the total costs are a summation of the total transaction costs and the total production costs, and that the total costs need to be minimised.
- *Single piece flow on the critical parts level*
  Single piece flow is not only applied to the complete product, but it is projected down to the critical parts level. Mechanics are scheduled per process stage and parts flow through the processes as they become available. Parts are not batched between process stages, and therefore it could be that some parts already enter a process when other parts of the same unit are still being disassembled. This transactional change does not only affect the new ACM, but also the other ACMs.

Results of simulation for ATAT and OTP

The simulation showed that the level 4 changes have a large impact on the measures presented in the improved simulation results. Figure 7 shows the results on the general LSS indicators of ATAT and OTP. ATAT is the TAT minus the hold-up time the customer is responsible for. Figure 7 also shows the indexed values of average ATATs and OTPs for the following detailed cases: 1) the 5 Other ACMs combined, 2) all new ACMs together, 3) new ACMs having Repair as work scope, 4) new

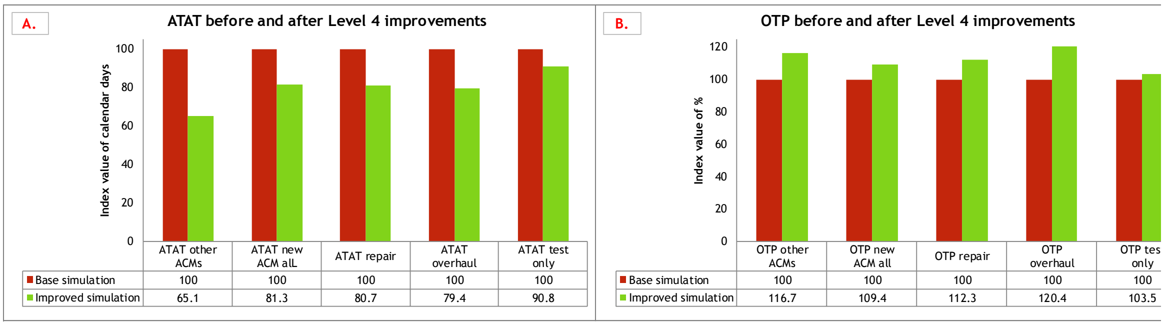

Figure 7. Indexed ATAT and OTP of the simulation runs before and after the Level 4 improvements

ACMs having Overhaul as work scope, and 5) new ACMs having Test Only as work scope. It can be observed that all indicators have improved for the final simulation compared with the base simulation. The new ACM process line improved with almost 19% on average according to the graph in figure 7. Level 4 improvement of the performance increase must be read relative to 100% of the base line simulation.

Scenarios performed with the base and final simulation

In order to demonstrate how the simulation models behave, five scenarios are performed on both the base and final simulation. The results are presented

- *Scenario change 1; theoretical upper performance boundary of the ACM process.* This scenario demonstrates the theoretical upper performance boundary of the new isolated ACM process line based upon the current product budget, the same initial inventory levels, and also the same amount of approved and authorised mechanics available for the process.
- *Scenario change 2; flooding the ACM process with incoming products*. This scenario entails flooding the simulation with new incoming ACMs in order to get an indication when the system would 'choke', and what the maximum throughput of the assembly line could be. The numbers of the various available transportation carts are all set to a level such that they will not be the bottle neck of the system.
- *Scenario change 3; flooding the new ACM process with a theoretical upper boundary.* This scenario is a combination of scenarios 1 and 2. It entails flooding scenario 1 with incoming new ACMs as specified in scenario 2. With this scenario it is determined what theoretical maximum throughput, or value flow, the isolated ACM process line could handle.
- *Scenario change 4; assigning an additional Technician for testing of other ACMs*. This scenario shows the impact of extra personnel and/or investing in training for approvals/authorisations.
- *Scenario 5: no stock, only housing set;* This scenario shows that without inventory it is for the improved model still possible to achieve relatively high OTPs. This proves that the JIT practice of the final model compared to the base best practice model are highly improved.

Results of scenarios with new found indicators T/FA, GM/FA and I/FA.

The relational measurement points for each of the changes (1-4) are projected in order to visualize their impact within the three graphs in figure 8. In each graph, alpha line is connected to the measurement point of the baseline simulation model. The simulations were modelled according to actual future budgets from the company; as such a restricted maximum exists for the total output. As the total output of the new ACM with the baseline model approaches the total budget already, *T/FA* remains constant when improving the system. The following can be observed from the graphs in figure 8 for the relations between the Lean Transaction Cost Efficiency indicators; T/FA, GM/FA, and I/FA as a result of the changes.

- T/FA vs. GM/FA; the GM is maximized due to additional transactions (change 4) by work orders up to the boundary capacity of the system. It shows the maximum utilization of the fixed assets for the system. The final performance is located on the right upper side of the graph relative to the index 100.
- *T/FA* vs. *I/FA*; shorter lead times for parts ordering, through negotiation, cooperation, and a higher level of supplier involvement allows for lower inventory levels. This causes a better utilization of inventory. The final performance is located at the left side of the graph relative to the index 100. The value of I/FA has been more than halved due to improvement of inventory

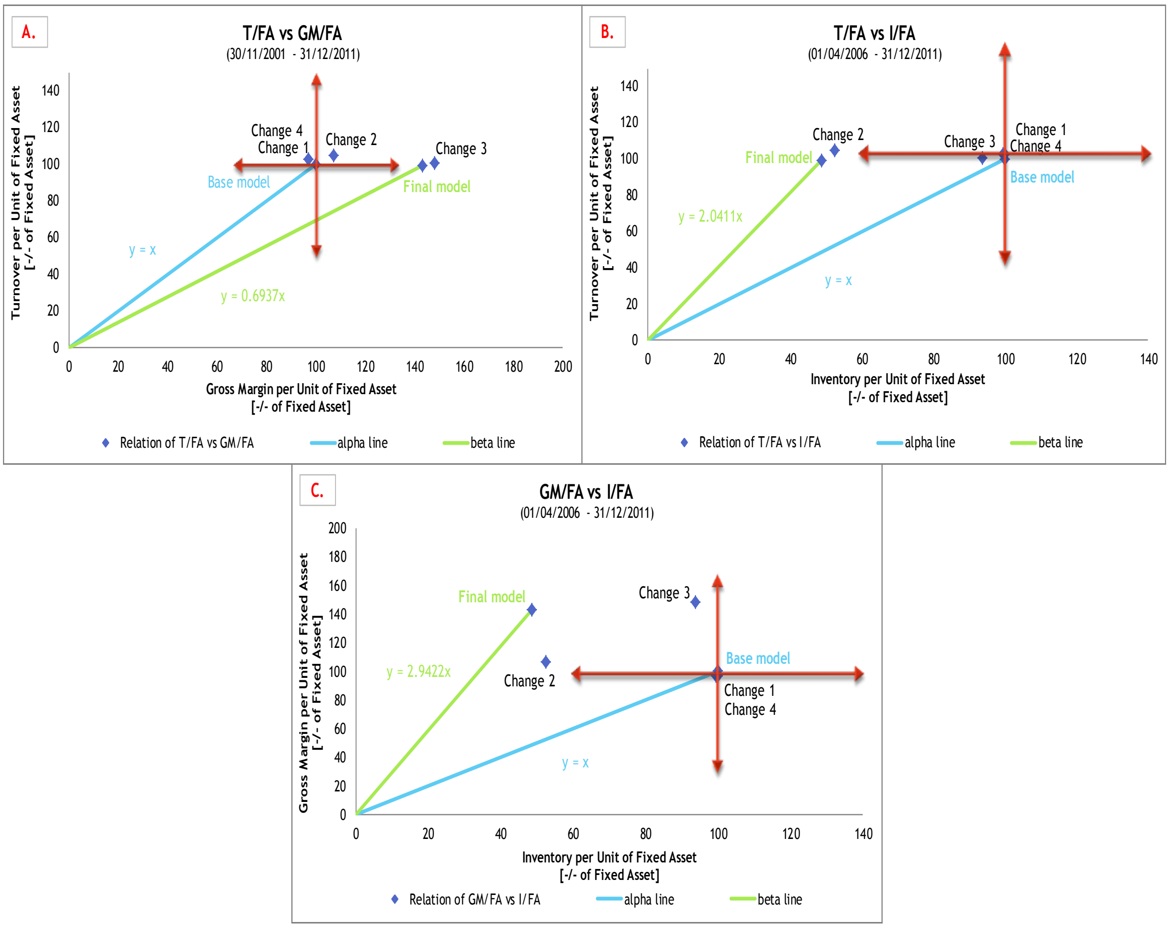

Figure 8. Impact of the individual Level 4 changes and combined effect in the final model

turns. Main contributor is change 2, in which specifically the inventory management is reviewed.

- *GM/FA* vs. *I/FA*; the shorter lead times of parts as mentioned regarding T/FA-I/FA, the positive effect on GM/FA can be expected. The final performance is located at the upper left side of the graph relative to the index 100. Relative to the baseline model the increase is approx. 50% according to the graph whilst the I/FA was halved.

Discussions

However there is a remarkable improvement in performance from the year 2006 to 2008 as presented in figures 3,4, and 5, the question was raised if this can be accredited to lean implementation only. In the first place this measurement needs to be tested with other cases in the MRO service industry by further research as this measurement concerns one SME Company however the measurement spanned an 11 year period. Secondly, the moment of lean implementation in 2007 can be identified by the graphs representing the performance on known indicators ATAT and OTP. The improvements measured with these indicators are in line with the improvement measured with the new found indicators. Thirdly, exogenous factors such as changing market demand may have influenced the results. However the airline industry has been changed over the past due to liberalization of state monopolies and the coming venue of low cost carriers, MRO services for high complex products such as ACM's and APU's is growing due to the production increase of aircraft during the last 15 years. Regarding endogenous factors, there were no exceptional additional investments in equipment which can explain for the exceptional performance improvement. It is plausible more resources such as personnel have been called upon to cope with increasing customer demand which may have influenced the results. However, this will reflect the gross margin.

Furthermore, the indicators are tested by simulation for the continuous improvement scenarios. The results of the changes to improve on the baseline simulation are indicated with the alpha line, the results of the changes of improvement on the final simulation are indicated with the beta line in figure 8, presenting the final level 4 changes for the final simulation model. Since simulation takes place in a virtual environment, different scenarios – changes can be implemented and evaluated much easier and cost effective than it would in real-life. After the virtual improvements new performances result from the simulation. The outcome can be projected in the quadrant graphs in figure 9. Comparing α and ß, or the slopes, gives an indication of whether the relation between the indicators T/FA, GM/FA and I/FA is better than before the change. It depends on the x and y axis indicators whether α < ß or α > ß indicate an improvement. The reasoning have been made on whether the angle improved, got closer to a certain target set, or got better than a target that was set. As such different scenarios can be compared. The first simulation outputs served as base line measurement to be put in the model proposed by figure 9. The x1 and y1 are set by this baseline measurement, which serves as a local optimum. As such, x1 and y1 axes form the quadrant boundaries. The center line through the point results in the angle α, indicating the present relation between the variables on the axes.

Statements can be made on whether the angle improved, got closer to a certain target set, or got perhaps better than a target that was set. It is also a possibility to perform multiple simulation iterations and to project the results in the graph. As such different scenarios can be compared. The performance of the (new) process can be evaluated by the simulation. Multiple simulation runs should provide with the same measurements if a process is stable. Quantitatively the improvement can be assessed to some extend by the statistical outputs of the simulation, for example the average, minimum value, maximum value, and the half width value. The half width value provides with the range within which 95% of the measurements averages fall and is therefore an important indicator for stability. An iterative simulation process evaluated by a general analysis, the Lean Transaction Cost Efficiency indicators, and the proposed quadrants model provides with a method to improve and validate new processes.

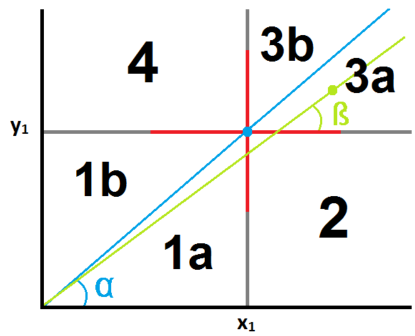

Figure 9 . Measurement and prediction of a new process by simulation

For this research relations between indicators can be applied as per figure 8.

- *T/FA* vs. *GM/FA*: The final measurement is located in quadrant 3. With α > ß this places the measurement in part 3a, which is the most preferred part. For this relation α > ß indicates that the improved system performs better on this relationship with respect to the base measurement.
- *T/FA* vs. *I/FA*: The final measurement is located in quadrant 4, which also automatically means that α < ß. With α < ß the improved simulated system performs better on this relationship with respect to the base measurement, thereby is quadrant 4 preferred the most for the final measurement to be located in.
- *GM/FA* vs. *I/FA*: The final measurement is located in quadrant 4, which also automatically means that α < ß. With α < ß the improved simulated system performs better on this relationship with respect to the base measurement and similar to the previous relation is quadrant 4 preferred the most for the final measurement to be located in.

Managerial implications

The simulation perspective opens four interesting implications for managers. Firstly, the simulation tool offers the management the capability to discuss the effect of making changes to assets and resources before deciding to invest in these. Secondly, managers can determine the progress in operations performance by monitoring the positions in the graphs through the years. By monitoring the position in the quadrant according figure 8, managers can adjust assets and resources to influence operations performance. The lean implementation strategy framework (figure 10) shows for instance that an increase of turnover due to growth of market share may harm the benefit or GM which results in a position in quadrant 4. Once the operations performance is positioned in quadrant 1 the aim is to move to quadrant 3 by an improved future state process. The Lean Implementation Strategy framework guides the managers for finding the balance between T/FA and GM/FA under influence of I/FA. Thirdly, the quadrant perspective can form the basis for developing a benchmark tool for maintenance service companies. In the fourth place the process simulation can form the basis for the design of a Greenfield Lay Out of a future state process and factory.

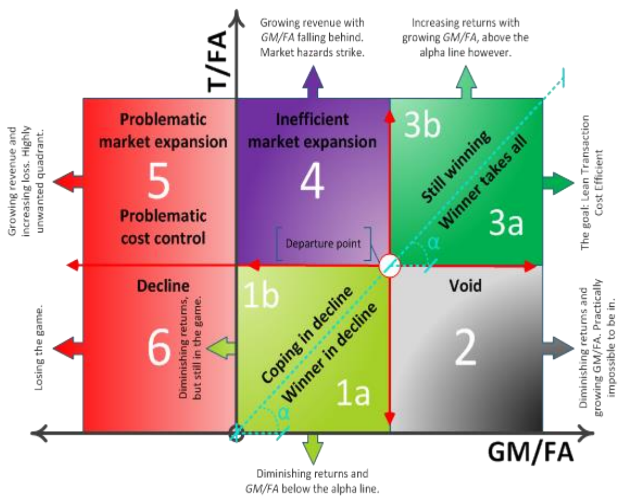

Figure 10: Lean Implementation Strategy framework

Conclusions

This research learned from literature that measuring lean implementation through time from a financial economic perspective was missing. From literature it was derived that Lean implementation not always leads to the benefits it claims. However, if there is commitment by the management with a top down approach it could be successful. In this case the management took leadership to implement lean in 2007. Support was found for the relation between cultural and organizational aspects like lean implementation, operational performance and fixed assets. The airline industry showed links between turnaround time and on time performance in relation with utilization of the fixed assets like Ryanair and EasyJet. From the analysis it can be concluded that by adding the fixed assets perspective, new indicators could be developed to measure operational performance under influence of lean implementation for a maintenance service company in the airline industry. Lean implementation is embodied by cycle time (ATAT) and on time performance (OTP). By introducing fixed assets in combination with turnover, inventory and gross margin, operational performance can now be measured by the Lean Transaction Cost Efficiency Indicators.

Contribution to theory

The MRO service industry can be characterized by regulations and certifications due government laws for safety of the customers making use of airlines. As a result the products and services are of a high complex nature in combination with high asset specificity. The proposed main research question ; how to measure operations efficiency from an asset specificity perspective under influence of lean implementation for maintenance service companies in the aviaton industry, is answered with the indicators; Turnover per unit of Fixed Asset (T/FA), Gross Margin per unit of Fixed Asset (GM/FA) and Inventory per unit of Fixed Asset (I/FA). The indicators have an interrelation and form a model. The found indicators are adding asset specificity and complementary to the already known Lean Six Sigma indicator; cycle time or TAT (Turn Around Time). The indicator On Time Performance (OTP) can be added to the theory of Lean Six Sigma (Cutcher-Gershenfeld, 2004).

The model has been validated on company level by (a) observing significant correlation between the outcome of the model and the number of years that lean has been implemented at the sample set, and (b) by observing positive trend breaks in the performance variables. The model has been tested with a discrete event simulation for four model changes and 5 experimenting scenarios to identify the upper boundaries of the MRO service provider system. By means of four transactional alterations to a simulated fictive new ACM process it is shown that both the operations performance on the general

Lean Six Sigma indicators and the Lean Transaction Cost Efficiency indicators are useful to determine the upper boundaries of the value system. From the analysis and simulation the following conclusions can be drawn:

- The found indicators were significant through time over the period 2007-2011. The indicators are interrelated and form a model.
- The slope of the trend line was positive indicating a positive change on the performance of the separate indicators. The gross margin per unit of fixed asset (GM/FA) increased with 250%, the turnover per fixed asset (T/FA) increased with 433%, and the inventory per unit of fixed assets (*I/FA*) increased with 177% over the period 2001-2011.
- Remarkable improvement between the phase before the implementation of Lean Six Sigma up to 2007 and the sustainment phase, which emerged from 2008 up to 2011 was measured with the new indicators.
- The preliminary model enables the implementation of changes to improve performance by scenario's and to identify the upper performance boundaries of the value system.

Contribution to practice

From a practical perspective the model helps to identify all relevant processes, as well as to quantify these processes and to validate possible future state systems which is a useful tool for Lean Six Sigma experts. With the analysis it would be possible to further develop this model for the managers as well as consultants as a tool for business planning. By testing scenario's it is possible to design improved processes without disrupting current operations. As such, a new process can be balanced from a Lean and transactional perspective before it may be implemented in reality.

Further research

The model needs to be validated on more MRO service companies in the airline industry. It can also be further developed for other type of service industries like hospitals for patient care services as well as manufacturing industries.

The costing function underlying the Gross Margin (*GM*) used in the indicator *GM/FA* is limited in its definition. *GM* is defined as the difference between turnover and the summation of material costs and value added labor cost. Further research could expand the cost function with for example material holding costs, employee idle costs, and other indirect costs. By doing so, results would be more accurate.

Asset specificity is the most crucial factor in TCE. In order to provide for an empirical measurement and indication of transaction costs, the book value of the MRO company's fixed assets is taken as a proxy for the asset specificity. Intangible fixed assets like company brand name or intrinsic employee knowledge have not been investigated in this research and are not included in *FA*. The key problem of measuring intangible assets is that they influence the results only in an indirect manner, mostly in the form of multi-level cause- and effect-relationships. However, if future developments allow for displaying these cause- and effect-relationships regarding both tangible and intangible value creation potentials, this could refine the definition of asset specificity used in this research.

Annex: Tables 1 and 2

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