



Rolls-Royce®

The Investigation of Lean Philosophies to Optimise the Flow of Work in Progress within Bristol Turbine Facility, Rolls-Royce.

Postgraduate Research Method

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2 TABLE OF ACRONYMS

RR – Rolls-Royce

BTF -Bristol Turbines Facility

WIP – Work in Progress

NWIP – Normal Work in Progress

SMWIP – Slow Moving Work in Progress

TPS – Toyota Production System

TPM – Total Productive Maintenance

PDCA – Plan, Do, Check, Act

TOC – Theory of Constraints

TQM - Total Quality Management

VSM – Value Stream Mapping

SAP - Systems Applications and Products in Data Processing

JIT – Just in Time

SMED – Single Minute Exchange of Dies

3 INTRODUCTION

The goal of every manufacturing business to make money. This is achieved by producing a product to meet customer demands at the lowest possible cost. To accomplish this goal, a business must have a manufacturing process optimised that it only adds value to the product thus having no excessive non-value-adding cost. To meet the goal of making money, a manufacturing business must see improvements in three categories: flow, operational cost and inventory. If an improvement does not fall into these three categories it is very unlikely that it will result in the business making more money in the long term (Goldratt, 2009).

This is the research proposal of the investigation of lean philosophies to optimise the flow of work in progress within the Bristol turbine facility at Rolls-Royce. Within BTF there is an inherent problem with the flow of work in progress through the business. Many work centres are blocked or starved of WIP which indicates that there are imbalances in the manufacturing process. These imbalances of WIP throughout the process have associated non-value-adding costs which every manufacturing company will want to eliminate or reduce. The research carried out will be an analysis of how WIP flows through BTF and what work centres are blocked or starved and for how long. Different types of manufacturing analysis of these imbalances will determine the course of action.

Rolls-Royce defines two types of work in progress, slow-moving WIP and normal WIP. NWIP can be static for an inventory cost-benefit but has the availability to be processed when required. While SMWIP is not easily processed due to other factors thus causing imbalances of flow. RR define SMWIP as WIP which has been static for longer than 240 working hours. The project's main objective is to optimise the manufacturing process to increase the availability of SMWIP thus allowing it to become NWIP. As a figure, it is to reduce SMWIP to twenty per cent of the total value of WIP by the first quarter of 2022.

The SMWIP is impacting the output of BTF. With this decreased output and higher non-value-adding costs, it is not a sustainable manufacturing model. The SMWIP through the business needs to be eliminated and a process put in place to stop such reoccurrences. If the rising cost and lower output continue then work may be relocated to other sites and BTF may not be considered viable for future projects.

Improvements in manufacturing have been around since the start of the industrial revolution. The most notable has been in the automotive industry with the likes of Ford Motor Company and Toyota Motor Cooperation (Ford Motor Company, 2021), (Toyota Motor Corporation, 2021). This is achieved by continually improving the process or the pursuit of true north as Toyota call it (Liker & Convis, 2011). With any deviation of their production system being addressed. This will ensure that a business is always adapting to the ever-changing market. The appearance of SMWIP through RR is a clear deviation from the production system and may uncover many underlying issues in the process which large volumes of inventory can cover-up.

By optimising the flow of WIP through BTF, improvement can be measured in areas such as:

- Production flow
- Inventory
- Cash flow
- Operational costs
- Capacity

3.1 CONSIDERATIONS OF ISSUE

To understand the importance of WIP and the location of it, the measure of the value of WIP must first be understood. RR define WIP as a product within the business which has not had all it is value-added. Therefore, a single product at the start will have a far lower value than one at the end. RR

calculate the value of WIP based on how much value has been added to it by processing. This can also be determined by the position in the manufacturing process or work centre location.

At the start of the manufacturing process, volume commonly is high but value due to it being early in the process it has relatively low value. At the end of the manufacturing process, the value is high, but the volume tends to be lower. The measure of the success of this project will be based on the reduction of the value of the SMWIP. From a business perspective targeting the high-value areas would satisfy the goals set by management. However, it may not solve the inherent issue of the flow of WIP throughout BTF.

One of the greatest issues of this project is if any changes are to be made that it cannot reduce output. The repercussions of having even further reduced output could be costly with the chance of ceasing production at another facility. Any processes that are improved will be beta tested and verified through sample runs. However, due to the nature of the process stream no matter the testing other work centres may be affected downstream.

3.2 RESEARCH VARIABLES:

3.2.1 Dependent Variables

- Maximum capacity of each operation - The operational time of each operation is fixed and will be consistent throughout the project.
- The product types - Will be production parts only, no research and development work will be considered in the research.
- The number of production staff will remain consistent
- The demand of parts – Build schedule
- Available production time - Shift change over, breaks and weekends
- WIP – Value costing of WIP

3.2.2 Independent variables

- Quality checks/issues – Type of check and failures
- Breakdowns – Asset breakdown or out of specification
- Production staff behaviour – External factors
- Process conformity – Production staff following the correct process
- Movement of WIP – Speed and storage of WIP
- Manual operations – Non-standard blade fettling
- Set up times - Time to set up work centres

3.3 HYPOTHESIS

The implementation of a lean philosophy will optimise the flow of work in progress, increase available capacity and reducing inventory in Bristol Turbines facility.

4 LITERATURE REVIEW

The literature that will support the research of this project will be the lean philosophy and the application in other industry. Lean as a philosophy is well known and has been studied worldwide.

4.1 LEAN PHILOSOPHY: CONCEPT, PRINCIPLES AND TECHNIQUES

The implementation of the lean philosophy has improvements in terms of inventory reduction, customer satisfaction, flow, lead time and waste reduction. This is evident in studies such as the European food industry (Dora, et al., 2013), Operational management (Fullerton, et al., 2014), Health Service (Ingelsson & Mårtensson, 2014) and Service sector (Teehan & Tucker, 2014)

Lean in terms of manufacturing was first truly integrated in 1913 by Henry Ford with his flow production (Wormach, 2002). This form of manufacturing changed the world for the better. However, the main constraint with Ford's new method of manufacturing came in the form of variety. Ford was unable to offer a different model the Model T due to the constraints of the production line (Ford Motor Company, 2021).

Toyota at the time studied Ford's flow production and revised it to allow for the variation (Toyota, 2021). The Toyota Production System is said to be the birthplace of the lean philosophy and the creator was Taiichi Ohno in the 1950s (Monden, 1998), (Liker & Convis, 2011), however, not until research from Krafcik in 1998 at MIT was the term lean used (Krafcik, 1988). The study published in "*The machine that changed the world*" (Womack & Jones, 1990) concluded that Toyota was able to produce cars at a rate unseen in that time with half the resources, due to the lean philosophy. In their second publication of "*Lean thinking*", it was found that the lean philosophy or TPS was the way Toyota only adds value to its product by eliminating waste (Womach & Jones, 1996).

After Wormack's research, it was identified that there are five principles of lean:

1. Identify customer value – Understand what the customer is willing to pay for
2. Map the value stream – Map the process to add value to the customer, eliminate processes that do not add value.
3. Create Flow – Have a continuous flowing valuing adding processes
4. Establish Pull – Create products only when needed "Just in time"
5. Seek Perfection – A continuous improvement environment, the pursuit of true north.

(Wormach, 2002)

These principles can be seen as a derivate of the TPS philosophy which has evolved since its introduction but is broken into 12 pillars:

- Poka-Yoke – Fail-safe which stops production if an error occurs.
- Hansei – The process of learning from your mistake.
- Andon – Visual aid for action.
- Jidoka: *"that a machine must come to a safe stop whenever an abnormality occurs"* (Toyota, 2021).
- Just-In-Time: *Making only "what is needed, when it is needed, and in the amount is needed"* (Toyota, 2021)
- Heijunka – Having the correct number of parts to build the correct number of products to meet customer demand.
- Kaizen – The philosophy of continuous improvement.
- Genchi Genbutsu – The idea that the best way to solve a problem is to see it.
- Nemawashi – A decision should not be made by an individual but by a team.

- Kanban – 6 rules of production.” 1) *Never pass on defects*; 2) *Take only what is required*; 3) *Produce exact quantity required*; 4) *Level the production*; 5) *Fine-tune production*; 6) *Stabilise and rationalise the process.*” (Toyota, 2021)
- Muda, Muri, Mura – Muda Eliminating the 7 wastes: Transportation, inventory, motion, waiting, over-processing, overproduction and defects. Muri – Even distribution of production processes. Mura – Diversly trained workers for operation coherence.
- Genba – Where the work is carried out.

(Toyota, 2021), (Toyota, 2021)

To achieve the principles of Womack and the TPS philosophy various studies and literature have proposed different methods and techniques to be able to implement the lean philosophy. (Bin, et al., 2016), (Gurumurthy & Kodali, 2011), (Dinis-Carvalho, et al., 2019), (Mackelprang & Nair, 2010), (Wickramasinghe & Perera, 2016), (Thurer, et al., 2019), (Jabbari, et al., 2020), (Hameri, 2011), (Simboli, et al., 2014), (Goldratt, 2009), (Gupta & Boyd, 2008) (Anil & Satish, 2019), (Nakajima, 1989), (Moreira & Garcez, 2013). With the literature taken into consideration, the following is a list of methodologies, concepts and models that would be necessary to implement the lean philosophy.

4.1.1 Value Stream Mapping (VSM)

This is the process of analysing all the actions required (value-adding and nonvalue-adding) to bring a product from raw material through the business and to the customer (Rother & Shook, 1999), (Gurumurthy & Kodali, 2011).

4.1.2 Kanban

The six rules of production .” 1) *Never pass on defects*; 2) *Take only what is required*; 3) *Produce exact quantity required*; 4) *Level the production*; 5) *Fine-tune production*; 6) *Stabilise and rationalise the process.*” (Toyota, 2021)

4.1.3 Kaizen

The concept of continuous improvement. Kaizen is a culture that encourages everyone to improve on a business and personal level. Kaizen is the pursuit of true north or perfection, the elimination of Muda or waste and improvements in the efficiency of the business. Kaizen can only be possible with standardised practices which aid in the identification of problems (Toyota, 2021), (Toyota, 2021), (Ohno, 1990).

4.1.4 Plan, Do, Check, Act (PDCA)

Is a method for the control and implementation of continuous improvements. It is a vital process to ensure that improvements are effective and implemented correctly.

Plan – 1) Identify problems; 2) Analysis cause; 3) Formulate potential countermeasures.

Do – 1) Develop implementation plan; 2) Communicate plan; 3) Execute the plan.

Check – 1) Monitor progress of implementation plan; 2) Modify plan if necessary; 3) Monitor results

Act – 1) Evaluate results; 2) Standardise effective countermeasures or start PDCA again.

(Ford Motor Company, 2019), (Prashar, 2017), (Chen & Li, 2019)

4.1.5 Total Productive Maintenance (TPM)

A standardized, proactive and disciplined system that engages all employees to maintain the integrity and availability of equipment, facilities and processes (Ford Motor Company, 2019). TPM aims to optimise the process of preventative, corrective and predictive maintenance to ensure equipment is working to its maximum efficiency with the least effect on production (Willmott, 1994). A TPM strategy aims to have autonomous maintenance by including production employees (Wickramasinghe & Perera, 2016), (Ford Motor Company, 2019), (Ahuja & Khamba, 2008).

4.1.6 Total Quality Management (TQM)

Is a concept of meeting customers standards by the management and continuous improvements in common processes and standards. In practice, TQM is the detection of non-conformities to the standard. Jidoka is a way of ceasing production from the use of poka-yoke and Andons to ensure that no defective products are passed on, which is rule one of Kanban. TQM is imperative of reduction of Muda (Toyota, 2021), (Toyota, 2021), (Ford Motor Company, 2019), (Modgil & Sharma, 2016).

4.1.7 Theory of Constraints (TOC)

The theory of constraints is a methodology of identifying constraints within a manufacturing system. The constraint can either be eliminated or the flow of the production can be balanced to the maximum output of the constraint. It hypothesises that a manufacturing system consists of links of which the previous link is a constraint of the next and the system is only as strong as the weakest link. The five steps of identifying and eliminating steps are: 1) Identify constraints; 2) Exploit constraints; 3) Subordinate and synchronise to the constraint; 4) Elevate the constraint; 5) Repeat process. (Gupta & Boyd, 2008), (Goldratt, 2009), (Rahman, 1998).

4.1.8 Takt Time

Takt time is the rate at which a business needs to complete products to meet the demand of the customer. Takt time gives the ability to optimise the production rate to ensure that there is no overproduction. Takt time is a fundamental part of Heijunka and Kanban, which aids in the reduction of Muda (Schneider, et al., 2015), (Keim, 2019).

4.1.9 Just in Time (JIT)

Just in time is a technique that coordinates *“what is needed, when it is needed, and in the amount is needed”* (Toyota, 2021). JIT reduces the generation, purchasing and holding of inventory that is not required. A JIT or pull system is a method of using customer demand triggers to start the production of a product of which the parts required are delivered just before they are needed. To apply this model effectively it relies on signals from the Kanban system (Toyota, 2021),. This is not just at a

manufacturing assembly level but at all levels of the supply chain. The JIT technique due to the low inventory levels give indications of imbalances in flow which would usually be hidden with excessive inventory (Mackelprang & Nair, 2010) (Holl, et al., 2013) (Bruce, et al., 2004) (Browne, et al., 1996).

4.1.10 Single Minute Exchange of Dies (SMED)

Is the process of reducing the lead time of the change of manufacturing processes from the current to the next product (da Silva & Filho, 2019). This gives the ability to reduce batch sizes and produce only what is necessary to meet demand; rule 3 of Kanban (Toyota, 2021). This reduction of lead-time will reduce the Muda of the process and reduce the interruption of flow or Mura. (Carrizo Moreira & Campos Silva Pais, 2011), (Bin Shafei & Bin Che Ani, 2019).

4.2 MANAGEMENT CULTURE

With the consideration of all the methodologies, concepts and models in section 4.1 it is important to understand that the implementation of these technical tools must be coupled with lean management. There is clear success in the lean philosophy as seen by the dominance of Toyota in the automotive industry (Forbes, 2019). However, there have been many failings in the implementation of these models (Albliwi, et al., 2014), (Schonberger, 2007), (Jadhav, et al., 2014), (Rahbek Gjerdrum Pedersen & Huniche, 2011), (Secchi & Camuffo, 2019), (Goldratt, 2009).

Since the early adoption of the lean philosophy, western companies have struggled to fully implement lean due to the challenge of the status quo. Even in the beginning, Taiichi Ohno also struggled to change the culture of Toyota to his lean methods (Liker & Convis, 2011). Research of case studies shows that no matter how hard the push of change to lean there will always be met with resistance (Kotter, 1995), (Kumar & Kumar, 2014), (Bhasin & Burcher, 2006), (Scherrer-Rathje, et al., 2009). The success of lean can be seen by many Japanese companies, where the lean philosophy is throughout the company and not just technical tools (Abdallah, et al., 2019), (Bhasin & Burcher, 2006). Companies that fail in sustaining lean is found to be down to, that lean is seen as a strategy rather than a

philosophy (Marksberry, 2012), (Jayamaha, et al., 2014). At Toyota, managers often are grown through the company starting at the lowest level. Through understanding of Genba, the lean philosophy is ingrained in them. A perfect example of the lean philosophy was the joint venture of Toyota and General Motors called NUMMI. Toyota recruited not based on previous experience, or roles but the attitude of the individual and if they were able to embrace the Toyota way of lean (Liker & Convis, 2011), (Marksberry, 2012). The research indicates that if lean is to be sustainable within a company it must be embraced as a philosophy or way of life. Failure to do so will result in the status quo of wasteful manufacturing.

5 METHODOLOGY

This methodology will try to give a path for the solution to RR's inherent issue with the flow of WIP through BTF. With the implementation of the research in concepts, models, analytic tools and philosophies the constraints of the manufacturing system can be identified and exploited to optimise flow and increase the efficiency of the system. Once the constraints of flow have been addressed the lean philosophy will be implemented to see if further optimisation is possible in the manufacturing process.

5.1 RESEARCH METHODOLOGY

The research conducted in this project will be based upon the collection of operational data with emphasis on WIP through work centres. Firstly the theoretical output and flow rate of the manufacturing process will be obtained to be the objective. This will then be analysed with the current output and flow rate of the process collected by Systems Application and Products Processing (SAP) and Asset management software: Maximo. The data on WIP will then be analysed based on product ID, location in the system, volume and static duration. This will be correlated with operation availability; customer demand; estimated and actual delivery date. The correlation of operational and delivery data will indicate the performance of BTF.

The data collected will allow for the identification of the constraints within the system, thus allowing the application of the models discussed in section 4.1. The process will be evaluated on a value-adding and nonvalue-adding basis to calculate the Muda in the process. The constraints of the system will be exploited and eliminated, then further analysis will be conducted to ensure it has been sustained.

Further data will be collected with regards to supply chain and customer demand to give a full understanding of the scale of the issue, of which some will be outside of BTF. After the scope of the

manufacturing system has been defined and boundaries set. The implementation of the lean philosophies will begin using Kaizen of the current process with PDCA as a method of ensuring that all improvements are correctly defined, implemented and measured.

5.2 PHILOSOPHY

The research carried out for the project will be prodomantly positivist nature due to the quantitative scientific values and is based on measurements. The captured data will from production data and quantifiable observations. However, due to the positivist approach based on measurements, aspects of this project such as the adoption of lean philosophy is not a measurable metric. Therefore a phenomenological approach will be taken to understand the adoption.

5.3 STRATEGY

The strategy of the research will be both inductive and deductive. The initial phase of the project will collect the data and identify patterns between WIP data, product streams, production data and operational availability to form a theory to resolve the issue of flow. Then the project will use a deductive approach by using theories detailed in section 4.1 and apply those theories to the data and to see if the hypotheses are correct.

5.4 VALIDITY OF DATA

The data capture used in this project will be collected from SAP and Maximo software. In the aerospace industry, the traceability of product data is a legal requirement thus the data would be assumed accurate and integral.

Due to the volume of products and the extensive products streams that data is being collected, the use of SAP is the method that would be deemed as the most time effective. Furthermore, due to the production being a 144 hour week, observational data will be limted.

5.5 DATA EVALUATION

5.5.1 Data Collection

Due to the complexity of data and factors of which affect it, the data will be collected in phases. The first phases will be based upon data local to BTF. To implement the lean philosophy, data will need to be obtained from the supply chain and customers.

5.5.2 Phase 1:

- Theoretical output and flow rate
- WIP data – Part ID, Location, Volume, Value, Static duration
- Product streams – Operations associated with Part
- Production data – Operational availability
- Capacity

Phase 1 will give an insight into the magnitude of the issue, and highlight key products and work centres. This data will be obtained using production software such as SAP, Maximo with process evaluation details.

5.5.3 Phase 2:

- Work centre cycle times
- Over equipment effectiveness
- Quality issues
- Value stream mapping

Phase 2 will give the data required to carry out the analysis of the constraints of the system. The data will be obtained using Maximo and TQM reports.

5.5.4 Phase 3:

- Collect data on production triggers

- Customer demands
- Expected delivery
- Supply chain and value stream
- Process adherence

Phase 3 will give a better understanding of how external factors may affect the flow of WIP from an external perspective. The data collected will be of a business nature and influence the application of the lean philosophy.

Due to the current downturn in the aerospace industry from the Covid-19 pandemic, historical data of production prior will be used. The historical data will support the collected current data to see if there are patterns in WIP even at reduced production.

6 RESULTS

The results of phase 1 will be used to analyse production flow and identify the constraints of the manufacturing process. At this point, a plan of how to exploit the constraints will be devised and implemented using the TOC and PDCA methods. Only then will the data from phase 2 be used to reduce the Muda in the processing by using VSM, Kaizen, TPM and TQM. This will allow the production flow to be balanced to the constraints of the system. The data from phase 3 will then be used to adopt the lean philosophy of Kanban, JIT and Takt time and optimise the manufacturing process to customer demand.

The hypothesis set out in this proposal will be tested at stages throughout the optimisation process to see if the implementation of the lean philosophy is a measurable success. The hypothesis may mature when the data is analysed and methods and concepts have been implemented to give a more measurable but specified outcome.

7 CONCLUSION

To conclude, there is extensive research on the implementation with tried and tested technical tools to use to optimise lean. The case studies researched in this proposal have shown that if the lean philosophy is implemented correctly can see benefits in cost reduction and customer satisfaction (Teehan & Tucker, 2014) (Abdallah, et al., 2019). Still, many companies fail to sustain lean as common practice (Goldratt, 2009) (Jadhav, et al., 2014). This is due to the resistance to change throughout the company even at a management level. With that in mind, the proposed changes that this project may generate at BTF will be based on changing the philosophy of how BTF operates. RR like many other companies are fully aware of the benefits of lean but still are yet to sustain such change. Until a substantial cost benefit is seen then it is very difficult to convince management that the lean is a viable option.

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