CLOUD MANUFACTURING MODEL TO OPTIMISE MANUFACTURING PERFORMANCE

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ABSTRACT

Being predicted as the future of modern manufacturing, cloud-based manufacturing has drawn the attention of researchers in academia and industry. Researches are being done towards transforming every service in to cloud based service-oriented manufacturing mode in the manufacturing industry. There are many challenges that would arise when travelling towards this paradigm shift which is being addressed by researchers, but there are very few researches that concentrate on the elastic capability of cloud. Elastic capability makes this paradigm unique from all the other approaches or technologies. If elasticity is not achievable then the necessity of migrating to cloud is unnecessary. So, it is imperative to identify if at all it is necessary to adopt cloud-based manufacturing mode and discuss the issues and challenges that would arise to achieve elasticity when shifting to this emerging manufacturing paradigm. This research explores the importance of adopting cloud-based manufacturing mode to improve manufacturing performance based on the competitive priorities such as cost, quality, delivery and flexibility and proposes an elasticity assessment tool to be included in the cloud-based manufacturing model for the users to assess the challenges and issues on the realisation of elasticity on the context of manufacturing, which is the novelty of this research. The contribution to knowledge is a clear understanding of the necessity of cloud based elastic manufacturing model in the manufacturing environment for the manufacturing SMEs to gain a competitive advantage by achieving the competitive priorities such as low-cost, high-quality, and on-time delivery. Finally, the research suggests the best combination of manufacturing parameters that has to be emphasised to improve the manufacturing performance and gain a competitive advantage.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

NIST - National Institute of Standards and Technology

SME – Small and Medium Enterprise

SLA – Service Level Agreement

SaaS- Software as a Service

IaaS – Infrastructure as a Service

PaaS – Platform as a Service

IoT – Internet of Things

DAMA – Design Anywhere, Manufacture Anywhere

ERP – Enterprise Resource Planning

MES -Manufacturing Execution Systems

OA - Operation Agility

TPLT – Total Production Lead Time

MR – Multiple Regression

MF – Machining Flexibility

BPR-Business Process Engineering

TQM – Total Quality Management

JIT – Just-in-Time

MRP – Material Requirement Planning

AI – Artificial Intelligence

SMART - Simple Multi Attribute Rating Technique

MCDM - Multiple-criteria Decision Analysis

CI- Confidence Intervals

Df – Degrees of Freedom (as argument)

MS – Mean Square

3M- Man, Machine, Material

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I cannot thank my family enough for the moral support, financial support and motivation they have given me throughout my education. I thank my close friends, who were there for me and uplifted me whenever I needed one. Finally, I would like to thank all who helped me in all ways, small or big, to help me reach this far.

DEDICATION

I dedicate this research first to GOD, who is my hope, my faith, my shield and my strength. Then I dedicate this research to my pillars of strength, my dad, my mum, my loving brother and my daughter, who supported me spiritually, mentally, financially and in every way to overcome all the obstacles and turn them into stepping stones and become of what I am today.

PART 1- INTRODUCTION

Chapter 1
Introduction

1.1 Summary and purpose:

This chapter describes the background, aim and objectives of the research. It explains the problems that instigated the research, and the description of aim and objectives. This chapter also provides the layout of the thesis and details of the structure for developing a tool for elasticity assessment of cloud-based manufacturing model for the use of small and medium enterprises to evaluate the necessity of moving to service-oriented cloud-based manufacturing model.

1.2 Research background

Due to the global economic downturn, manufacturing organizations worldwide are under enormous pressure to constantly innovate, compete and sustain competitive advantage. Manufacturing industry is not an exception to this challenge. In the past couple of decades, the manufacturing industry has matured significantly by using management strategies and practices such as Six Sigma, Lean Manufacturing, Total Quality Management, Agile Manufacturing and Just in Time. However, there is still scope to leverage the new technologies like virtualization, cloud computing to improve the efficiency of the manufacturing business processes. Cloud computing is empowering Information technology with its flexible, automated infrastructure and on-demand service models. In the recent years, the impact of cloud computing has begun to make waves in the manufacturing industry. Though the idea of implementing this service-oriented technology in the manufacturing environment sounds attractive, it is still a question of how this new cloud-based manufacturing paradigm would improve manufacturing performance and persuade the traditional manufacturing firms to be a part of cloud-based manufacturing system in real time. Unless there is a clear understanding of the cloud-based manufacturing model, its characteristics, capabilities, advantages, uncertainties, challenges, the maximum potential of cloud computing operating model towards the contribution of the improvement in the manufacturing performance can never be realised in practice. This lack of understanding of the capabilities of cloud operating model and cloud-based manufacturing model and its capability to improve manufacturing performance has been a motivation for this research.

1.3 The Research Problem and Its Significance

There have been enormous challenges and opportunities facing the manufacturing industry in the 21st century. Manufacturers are driven by the competition for low cost resources and high-quality products at a faster time to market. TQCSEFK (T – fastest Time to market, C – lowest Cost, S – best Service, E – cleanest Environment, F – greatest Flexibility, K- high Knowledge) has become the desired goal of any organization in this globalized economy (Tao et al, 2010). To achieve this goal, several advanced manufacturing models and technologies like Computer Integrated Manufacturing, Agile Manufacturing, Networked Manufacturing, Virtual Manufacturing, Global Manufacturing, Application Service Provider, Collaborative Manufacturing Network, Lean Manufacturing, Digital Manufacturing, Industrial Product–Service System, Manufacturing Grid, and Crowd Sourcing have been introduced in the manufacturing sector.

Tao et al. (2011) states that, though each of the above-mentioned advanced manufacturing technologies has its own emphasis, and they all centre on network, resource sharing, and cooperative work. Despite their great contributions to the development of manufacturing information, issues like allocation of manufacturing resources, enhancing resource utilization, reducing the resource and energy consumption, and effective transformation from production-oriented manufacturing to service oriented manufacturing are still not effectively addressed, which hindered the efficient implementation of these manufacturing models. To address these challenges, combination of newly emerged technologies like cloud computing and the existing advanced manufacturing technologies has been proposed and is called as cloud manufacturing (Bohu et al, 2010a).

In the recent years, a new virtualized, service-oriented computing technology called cloud computing has emerged in the field of information technology (Kang and Weimin, 2009). ’Cloud technology has emerged as a new paradigm to provide on-demand services in science, engineering and commerce, anywhere anytime’ (Liu, 2011). In cloud computing, computing resources are virtualized and are provided as unified services from a large-scale resource pool.

Third-party service providers like professional IT and networking companies have computing repositories and service centres, where “clouds” of virtualized resources are offered as services. Cloud based manufacturing has the same operating model as cloud computing where the cloud computing resources are replaced with manufacturing resources. This would offer new ways to a networked, collaborative service-oriented, elastic manufacturing mode which will be highly efficient with low energy consumption (Bohu et al, 2010a).

Though the proposed new manufacturing models has its own advantages like effective resource utilization, reduced resource and energy consumption, on-demand use of manufacturing resources and ability, there are many challenges and performance issues involved in real-time implementation of this virtualized, service-oriented technology (Wang et al, 2012).

The challenges include lack of standardized models, realisation of capabilities, abilities, advantages, disadvantages, safety and security issues to effectively implement this new technique in the manufacturing environment (Bohu, 2010b; Yinglei et al, 2011, Tao et al, 2011). This research aims to critically analyse the existing advanced manufacturing models and propose the new aspect of cloud-based manufacturing model emphasizing elasticity, which is the key characteristic of cloud computing and provide a virtualized, networked, service-oriented, distributed manufacturing environment to improve manufacturing performance. This research is focussed on manufacturing SMEs rather than larger companies. Because unlike large companies, small firms frequently suffer from lack of in-house facilities, and availability of resources and management support to provide the product delivery on-time and at the same time with low cost production.

1.4 Research aim and objectives

The aim of this research is to propose an elastic cloud-based manufacturing model, which would embed the elastic assessment tool into the manufacturing model, along with the existing advanced manufacturing technologies, in to the manufacturing business processes, to provide a high-quality product at lower production cost.

The objectives of the research are:

1. Carryout a literature study to assess the challenges faced by manufacturing SMEs.

2. Study and critically analyse the existing manufacturing models to assess their limitations in implementing the transformation from product-oriented to service-oriented manufacturing.

3. Ascertain the benefits of implementing the cloud computing technologies in the manufacturing business processes.

4. Propose a cloud-based elastic manufacturing model emphasising the elastic capability assessment.

5. Validate using WITNESS simulation software and R-Studio, where a set of manufacturing parameters will be identified and compared to find the best combination of variables to improve the manufacturing performance.

1.5 Research Methodology

This research work aims to design a novel manufacturing model to implement the cloud computing techniques along with existing manufacturing models, for manufacturing SMEs to gain a competitive advantage. To achieve the objectives of this research the following methods and techniques have been carried out:

- Review the literature to analyse the key performance indicators of manufacturing performance
- Review the literature to identify the problems faced by manufacturing SMEs in the digitized, complex, collaborative manufacturing environment.
- Review the published literature in the existing manufacturing technologies and the newly emerged computing technologies, their strengths and weaknesses, attempts made by other researchers to combine above technologies. Resources included internet, professional journals, books and conference proceedings.
- Propose a cloud-based elastic manufacturing model that embeds the elastic assessment tool.
- Validate using WITNESS simulation software and R-Studio.

1.6 Organisation of the thesis

The following Fig 1.1 illustrates the organisation of the thesis, which highlights the contribution to knowledge as well.

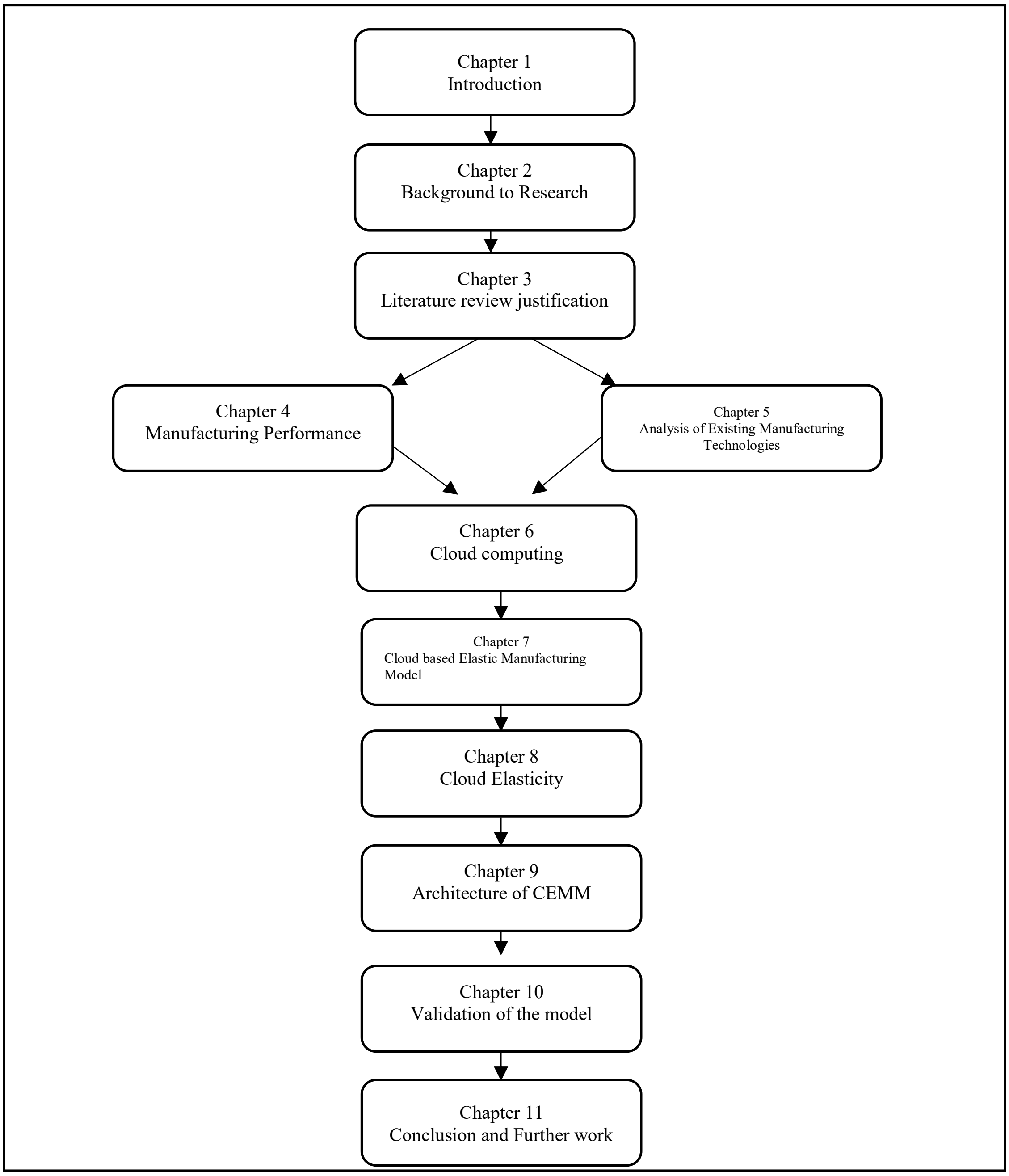

Fig 1. 1 Structure of the thesis

Part II- BACKGROUND TO RESEARCH

Chapter 2
Background to Research

"*Any tech investment that is done just for the sake of it, and not to address a particular challenge, is unlikely to succeed. The business case must come first, and it must be well understood*." – Phil Jones (The Telegraph, 2019)

2.1 Summary

As said in the quotation above, it is necessary for the decision makers in manufacturing SMEs to explore, understand, validate the necessity, challenges of new manufacturing technologies that are proposed to improve manufacturing performance at all the levels. This research concentrates on operational level decision making where the latest advanced cloud computing operating model is expected to optimise the manufacturing performance, especially for manufacturing SMEs on the perspective of cost, quality, on-time delivery, overall agility and networking. This chapter elaborates the background and motivation for this research, beginning from assessing the challenges faced by the small and medium enterprises in the current digital era, such as demand for high-quality, low cost production, challenges to sustain in the digitized manufacturing environment, necessity of moving towards collaborative globalized manufacturing, and finally the manufacturing technologies that help improve the manufacturing performance.

2.2 Challenges faced by the SMEs in the digital manufacturing era:

Being the backbone of manufacturing economy, manufacturing SMEs are expected to improve their operations by using innovations, new opportunities provided by computing, informatics. Manufacturing SMEs are forced to think ahead and explore innovative ways to tackle the challenges of improving their manufacturing operations. SMEs are not competitive enough when compared to the large enterprises who are more into innovations involving Information technology in every aspect of their manufacturing processes (Wuest et al, 2011). Literature study done in the involvement of SMEs in smart manufacturing implies that SMEs are not involved in the deployment of advanced manufacturing technologies and lack innovation and struggle to succeed without innovative strategy (Mittal et al, 2018)

2.2. 1 Demand for high quality, low cost product manufacturing:

For years and years, manufacturers have been following “more for less” tag line, which focusses on delivering high quality to the customers at lower cost. This “more for less” model has served manufacturers well, until the notion of improvements using technology so as to reducing the product life cycle, became a priority, thereby reducing the opportunity to acquire value from each improvement (Hagel et al., 2015). The challenges of achieving high quality cannot be ignored and this is one of the main obstacles existing in the manufacturing industry (The Manufacturer, 2019a). The current practices involved in the development of products are still based on cost/profit models, which also aims at achieving high quality at low cost and higher profit. This paradigm of development is unlikely to change any time soon (Li and Mehnen, 2013).

2.2. 2 The challenge of sustainability in the automotive manufacturing industry:

Sustainable manufacturing is the processing of resources into products with minimal negative environmental impact. Sustainability has become very essential to today's manufacturing systems and the new concern is working towards, how to evolve the existing manufacturing paradigms to meet new challenges. Sustainability has become a critical driving force shaping the future of manufacturing (Li and Mehnen, 2013). Economic sustainability is one of the pressing issues faced by manufacturers today, which implies that sustainable strategies and business models are imperative in the UK manufacturing industry to overcome all these latest manufacturing challenges (Found et al, 2006). There are several manufacturing business strategies, methodologies, tools and techniques like TQM, BPR, JIT and Lean and Six Sigma, that have been proposed and developed which are aimed at improving the productivity of the firms (Stamm, 2019). Despite introducing these methodologies to increase profits for the manufacturing firms, most of the firms still struggle to survive in the dynamic, ever demanding manufacturing environment (Hines, 2004). Though these proposed solutions profess to benefit the organisations in the short term, they don't help tackle the firms to sustain in the market in the long run. (Bateman, 2001). Shop floor employees bounce back to practising their older methodology by abandoning the new methodologies at the initial stage of implementation as the firm fail to strategize to merge the new methodology in an efficient way (Thomas et al, 2009)

"Lean" is one of the most popular method for improving business, which is practiced by at least 50% of UK manufacturers, who apply lean principles in at least part of their plant (EEF, 2001). The main principle of "Lean" is to eliminate waste and increase the flow of activities and thereby add value to the product (Womack and Jones,1996).

The "Lean" implementation is process-oriented and aims at waste reduction in a system and the down side of it is that it focusses only on a smaller number of conditions necessary for the sustainability of the business. Concerns about the sustainability of the "Lean" in a firm has grown in the recent years (Lean Enterprise Institute, 2009, Hines et al, 2004). This implies that there is a lack of a framework to deliver business sustainability (Pham, 2011).

2.2. 3 Impact of Information technology in the manufacturing industry:

For the past two decades we have been witnessing the impact of IT in our day to day lives and industries, and manufacturing industry is not an exception. IT has become a weapon to gain the competitive advantage because of the way IT has changed the way marketing, selling, buying and business environment works (Tewari et al, 2012). The manufacturing business environment has become dynamic and at the same time unpredictable and uncertain due to the impact of IT. Information technology in manufacturing industry has led firms to reduced cost, energy efficient, shortened manufacturing cycle, accelerated execution of operations, improved consistency, integration and instant exchange of data (Ai, 2011).

Manufacturers are using technology to improve operations by connecting devices on the shop floor to the usage of data analytics and supply chain planning tools (Plex.com, 2019). IT has been used in different phases of manufacturing processes like designing, planning, process and implementation. Manufacturing industry is becoming more efficient by new technological advances and by the computerized maintenance management systems, which helps to track, maintain, inspect and detect breakdowns, disruptions remotely and thereby increasing productivity (Reliableplant.com, 2019). The manufacturing industry has gained benefits of IT with automation, intelligent, interconnected manufacturing systems, in such a way that organisations are planning to re align their operational models to exploit the advanced new technologies. This is the reason for almost 55% of businesses in Europe have moved to Industry 4.0 and United States to Smart Manufacturing (Weygandt and Kristen, 2019). Information technology is used to integrate manufacturing activities from controlling operations in factories, providing tools to design product and process, model and simulate manufacturing operations (virtual manufacturing) to the integration of the whole enterprise, which proves that Information technology has a major and critical role in the information- intensive future of manufacturing ((Information Technology for Manufacturing, 1995).

2.2. 4 Emphasis on networking and resource sharing

With the development of the economy, which solely belongs to the consumer, the firms are facing a demanding, dynamic, ever changing and unpredictable market, which makes the decision makers to think that the traditional use of thinking and practise of following vertical integration, no longer suits the manufacturing industry, rather a manufacturing model, which will be demand-driven has to be established (Jiao and Zhao, 2012).

Fluctuations in demand and unpredictable disruptions in manufacturing environment have a great impact on logistical key figures. The resource sharing amongst manufacturing companies have been considered as a possible solution for this transport logistics. Becker et al (2016) refers to production machines as shared resources, where companies cooperate with each other and share their resources with an agreement. This has been proposed as an empowerment for companies to manage the disturbing unpredictable events by delegating orders to the partners who have accepted to cooperate. A manufacturing network is a coalition, either permanent or temporal, comprising production systems of geographically dispersed small and medium enterprises and/or original equipment manufacturers that collaborate in a shared value-chain to carry out joint manufacturing. The role of manufacturing companies has accordingly shifted from supplying domestic markets with products, via supplying international markets through export, to supply international markets through local manufacturing (Cheng et al., 2015a). Manufacturing system concepts have also evolved from a focus on the plant to the one on the manufacturing network.

The main goal of networking is to meet the fluctuating market demands quickly, to overcome the obstacles of regional boundaries, to break the limitations of time and space for the organisations to work collaboratively and operate in an efficient way (Xiong et al, 2008). The networked manufacturing has represented the trend of the manufacturing technique. Networking manufacturing firms has become the trend in the manufacturing environment (An and Feng, 2008). With the exacerbation of the competition in the global manufacturing market, the consumer demand for products is increasing day by day, the cost, quality, design and the delivery time has become the success identifier of competing manufacturing enterprises. With the advent of technologies that incorporates IT, networking, communication has improved in the recent times than several years back. It has become imperative for enterprises who possess NC machine tools to share their equipment resources for operational efficiency (He et al, 2008).

2.2. 5 The necessity of globalized manufacturing:

Despite globalization, which has provided vast opportunities in the plant and mechanical engineering sector, only few firms have transitioned from local export business model to global business model (Wyman, 2019). As the importance of emerging markets continues to increase, this transformation remains a key strategic challenge. To attain global competitiveness, firms would be ready to move factory to any part of the world, where the material, labour costs are comparatively less. This has led to the manufacturers to make parts in different locations, then assemble and finish the product elsewhere and sell them in the global market. Globalization of production has flourished, as there had been a gradual dismantling of barriers in trade and uninterrupted capital flows. Though an organisation could claim its product being produced from its own country, it cannot deny that its components may have come from various locations in the world (Islam, 2019). Businesses move actively towards globalization for diverse resources, cheaper production, and diverse market with loads of consumers for the products to sell to, which can be a competitive advantage (Blog.udemy.com, 2019).

To be more specific on the problems stated above, manufacturers are not known for investing heavily in the latest technologies on a regular basis. automation becomes more intelligent and manufacturers embrace machine-to-machine technology. This requires great increased storage space, data sharing and energy data management in order to achieve agility in business functions and sustain competitive advantage.

2.2. 6 Need for advanced manufacturing technologies:

Technology innovation has a critical impact on the industrial manufacturing. Innovation has not only made an impact on the bottom line or individual companies, rather on the productivity of many other sectors like construction, agriculture. It is reported that most innovative manufacturing firms have managed increase in revenues and innovation has made a dramatic impact on the competitiveness of the manufacturing firms (Pwc.com, 2013). Manufacturing innovation can take any form, from product to process improvement and it is key to outperform a competition. The continuous innovation in a manufacturing firm would help the firm gain a competitive advantage and hence achieve quicker turnaround time, with reduced waste levels, reduced downtime, improved product quality and potential for wider product range (nibusinessinfo.co.uk, n.d.). So, it becomes imperative for manufacturing firms to constantly innovate to sustain in the competitive manufacturing environment.

2.2. 7 Discussion

As discussed in this chapter there are various challenges that are faced my manufacturers especially manufacturing SMEs, who strive to sustain in the complex, dynamic, competitive manufacturing environment. There are several operational strategies that have been developed and been used in the manufacturing industry to achieve high-quality, low-cost product manufacture and thereby gain a competitive advantage. Since the intervention of established IT technologies have begun to make impact on the manufacturing industry, it becomes crucial for manufacturing SMEs to innovate with IT so as to sustain. This notion has led to this research where established advanced technologies like cloud computing along with existing advanced manufacturing technologies, can be used to help improve manufacturing competitiveness.

PART III - LITERATURE REVIEW

Chapter 3
Literature Review

3.1 Literature review - justification

The literature review methodology that has been used in this research is the "Theoretical review" due to the lack of relevant literature related to finding solutions to manufacturing issues (Adamson et al., 2017). As the research involves cloud-based manufacturing where the concept of involving cloud based operating model in the manufacturing field is still in theory.

The source of the literature that focussed on cloud-based manufacturing was very scarce, although it has gradually increased in the past few years (Hatema et al., 2018). Since the conceptualisation of cloud-based manufacturing started around 2010 (Henzel and Herzwurm, 2018), and the literature is very scarce, theoretical literature review has been used for the research.

3.2 Structure of the literature review

The Fig 3.1 represents the structure of the literature review in this dissertation which involved four stages as mentioned in the literature review guide by Labaree (2009).

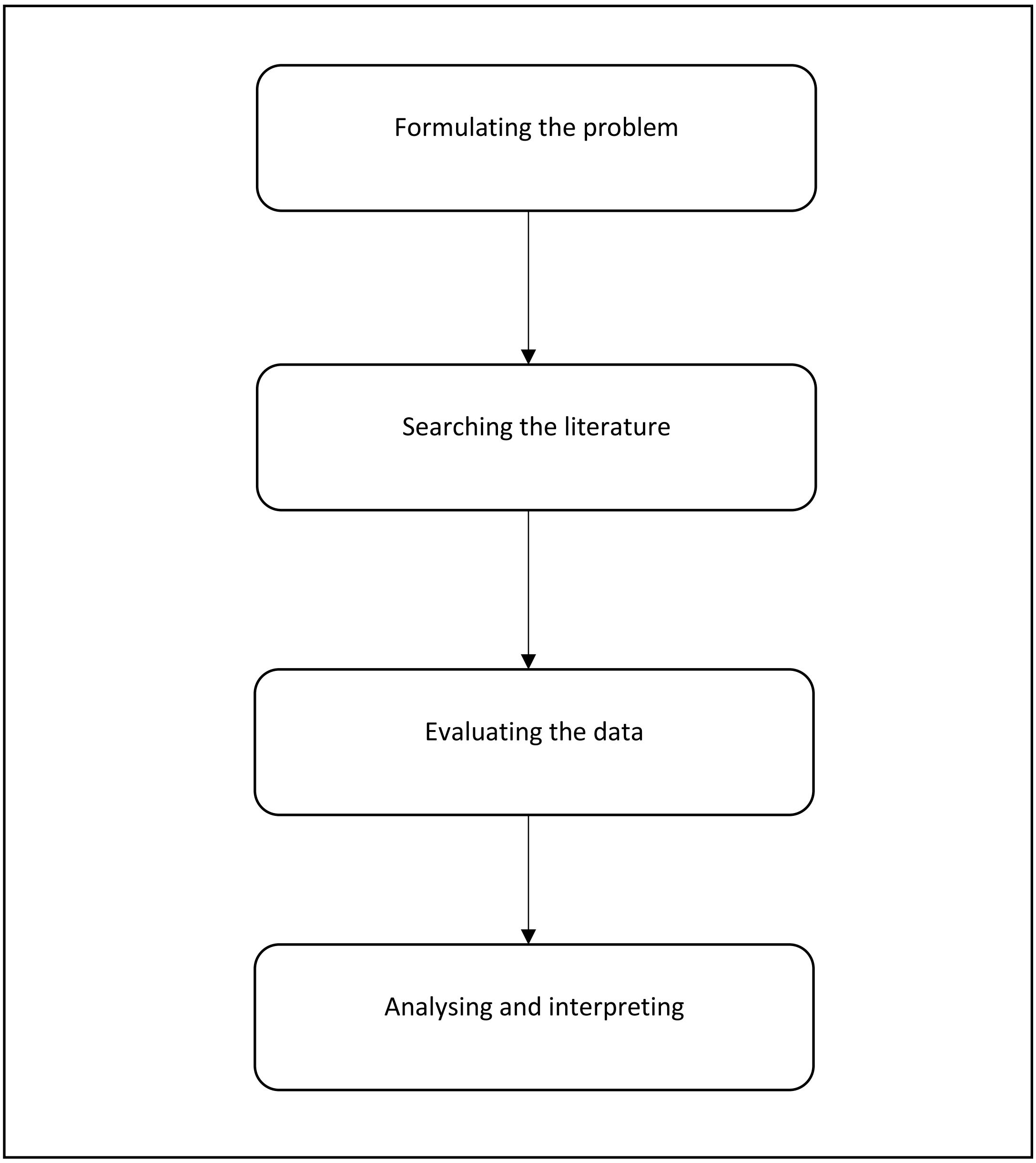

Fig 3. 1 Four stages in the development of literature review.

(source: Labaree, 2009)

- Formulating the problem:

  This phase involved the decision on the topic or the area of interest that is going to be examined and the components involved in it, that is, problems highlighted in manufacturing industry, especially targeting manufacturing SMEs, and how the interference of IT has made an impact in other industries and in manufacturing.

- Searching the literature:

  This phase involved the search for the materials or information that is relevant to the topic that has been chosen.
- Evaluating the data:

  This phase involved evaluating and finding what set of literature makes a significant contribution towards the topic that has been chosen and explored.
- Analyse and interpret

  This phase involved the discussion of the findings and conclusions relevant to the literature and also that which leads to the next stage of the research, based on the research gap identified.

3.3 Organisation the literature review

There are four main types of organising the literature review (Labaree, 2009). They are:

- Chronology of events
- By publication
- Thematic
- Methodological

The literature review in this dissertation is organised in the thematic way. First, the components that are responsible for improving a manufacturing performance and the issues that hinder the manufacturing SMEs were studied thoroughly. Simultaneously, studies related to the influence of technology in the field of manufacturing has been studied. Both studies have been connected and merged to arrive at a solution for improving manufacturing performance which is highlighted in the Fig 3.2.

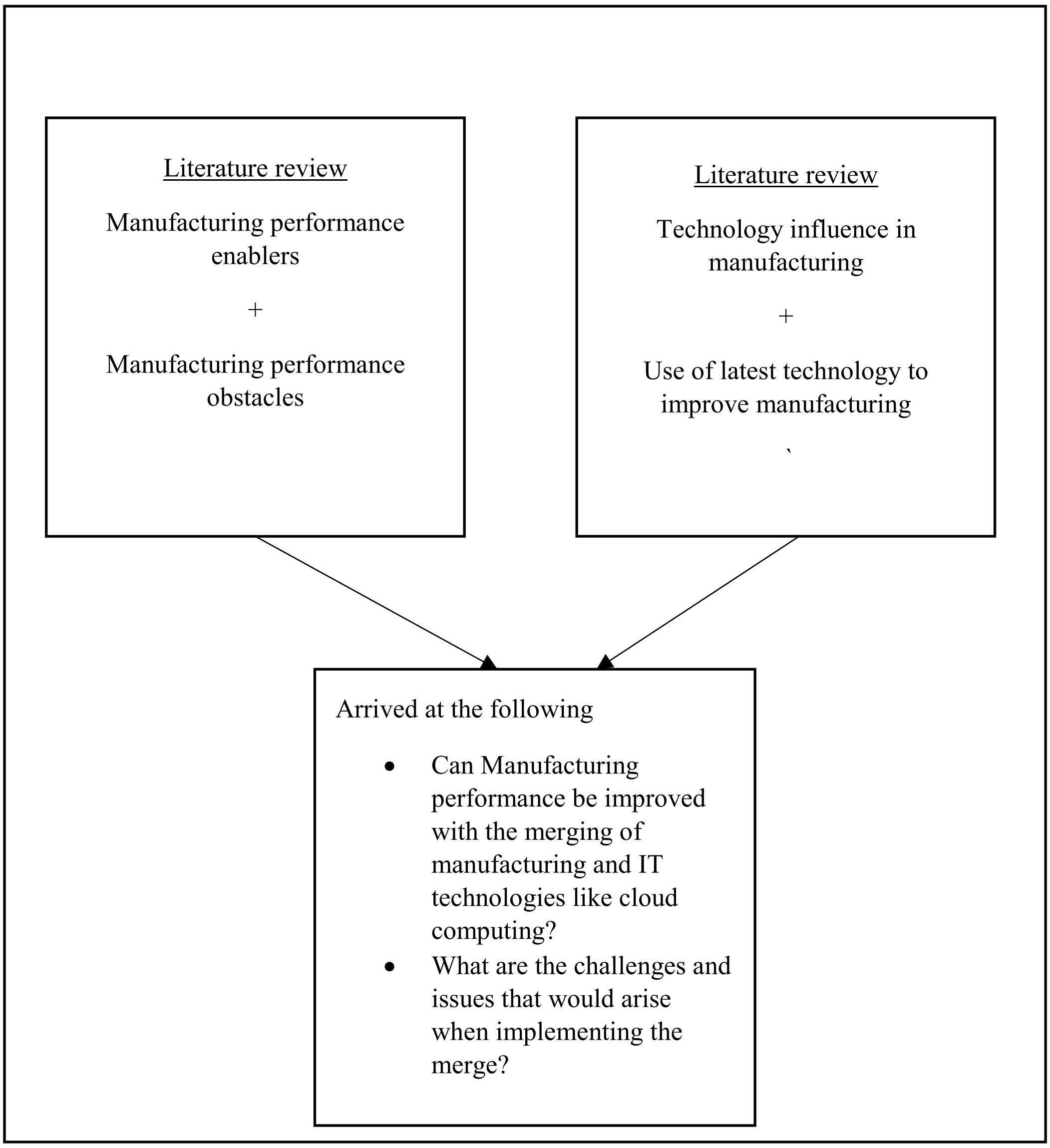

Fig 3. 2 Literature review organisation in the research

Chapter 4
Manufacturing Performance

4.1 Introduction

There is a strong correlation between manufacturing performance, strategy and capabilities. Competitive priorities of a firm include low cost, high quality, quick delivery, flexibility and service. A firm's capabilities are the means for achieving these competitive priorities. As the competitive priorities are dependent on the firm's capabilities, they have a strong impact on the manufacturing strategy and in turn on the manufacturing performance (Butt, 2009). These manufacturing capabilities are emphasised and employed by the operations strategy to support achieve its firm's mission. The key determinant of an organisation's capability to survive and gain a competitive advantage in the market, is the relationship between its firm's operations and strategy (Barnes, 2008). A firm's strategy should be built around the operations, where the operations help the firm to gain its competitive advantage through its performance and capability (OpenLearn, 2017). Operations strategy defines how an enterprise can survive and flourish in its environment in the long run. Operations strategy contributes to the capability of a firm to achieve its competitive advantage in the market place (Davis et al., 1999). Efficient operation strategy influences better manufacturing performance and improves the competitive advantage of a firm (Nurcahyo and Wibowo, 2015). Manufacturing enterprises are forced to re-engineer their operations strategy to sustain their competitiveness in the market (Gomes et al, 2004). Operation strategy refers to the choice of the business strategy, which helps the enterprise compete and sustain in the market (Casadesus-Masanell and Ricart, 2010). An efficient business strategy of an enterprise acts as the vital component of its competitive response to the market (Leitão et al., 2013).

4.2 Manufacturing strategy

Research on manufacturing strategy provides a structured decision-making step to improvise the economics of manufacturing and makes the firm more competitive (Hallgren, 2007). There are various definitions for manufacturing strategy by various authors. The Table 4.1 has been adapted and amended from Butt (2009) which gives an overview of all the definitions by various other authors. This research would like to choose the description of manufacturing strategy by Fine et al. (1985), to be ideal for the objective of the research.

Leong et al (1990) identifies that there are two important constituents of manufacturing strategy content such as competitive priorities and decision categories. These contents specify the decisions and actions of manufacturing strategy. Based on the content model adapted from (Butt, 2009), manufacturing strategy comprises of competitive priorities and decision strategies. These decision strategies can be either structural or infrastructural which would support the firm's competitive priorities.

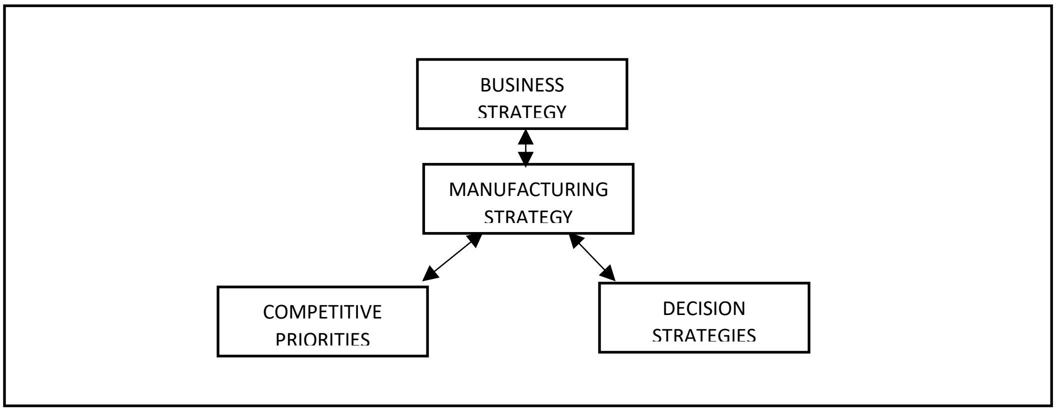

Fig 4. 1 Content model of manufacturing strategy

Fig 4.1 shows the relation between the business strategy, manufacturing strategy, competitive priorities and decision strategies based on Butt (2009), Hallgren (2007) and Leong et al. (1990).

Table 4. 1 Definitions of manufacturing strategy

Skinner, 1969	Exploiting certain properties of the manufacturing function as a competitive weapon
Hayes & Wheelwright, 1985	A sequence of decisions that over time, enables a business unit to achieve a desired manufacturing structure, infrastructure and set of specific capabilities
Fine & Hax, 1985	It is a critical part of the firm's corporate and business strategies, comprising a set of well-coordinated objectives and action programs aimed at securing a long-term sustainable advantage over competitors
Swamidass & Newell, 1987	The effective use of manufacturing strengths as a competitive weapon for the achievement of business and corporate goals
McGrath & Bequillard, 1989	The overall plan as to how the company should manufacture products on a worldwide basis to satisfy customer demand
Swink & Way, 1995	Decisions and plans affecting resources and policies directly related to sourcing, production, and delivery of tangible products
Berry *et al,* 1995	The choice of firm's investment in processes and infrastructure that enables it to make and supply its products to chosen markets
Cox and Blackstone, 1998	A collective pattern of decisions that acts upon the formulation and deployment of manufacturing resources. To be most effective, the manufacturing strategy should act in support of the overall strategic directions of the business and provide for competitive advantage
Brown, 1999	A driving force for continual improvements in competitive requirements/priorities and enable the firm to satisfy a wide variety of requirements.
Ward & Duray, 2000	Manufacturing-oriented dimensions that win orders
Cagliano *et al,* 2005	The configuration of strategic priorities the manufacturing system does or will pursue
Miltenburg,2008	A plan for moving a company from where it is to where it wants to be

(Adapted from Butt (2009))

4.3 Competitive priority:

Being considered as a critical component of manufacturing strategy (Jing and Sheng, 2008), the competitive priorities helps to build the operation strategy of a firm and in turn helps to analyse, assess the manufacturing performance of a firm. Rasi et al. (2015) emphasizes that competitive priorities are the critical operational dimensions which plays a huge role in the creation of supply chain.

The list of competitive priorities changed, as and when technology, customer expectations, market demand changed, over the years. In the beginning, Skinner considered only cost, quality, delivery and flexibility as competitive priorities (Skinner, 1969) to validate the operational performance of a manufacturing firm, which changed in the 90s where service was included along with the basic competitive priorities (Davis et al., 1999). Butt (2009) assesses the firm's manufacturing strategy based on the competitive priorities such as product quality, product cost, plant flexibility, product delivery time and product innovation. He considers them as the dimensions of manufacturing strategy. The terms competitive priority and competitive capability has been interchanged in the literature that has been studied, as various authors emphasize that intended capabilities as competitive priorities and realized capabilities as competitive capabilities (Ward et al, 1996). Despite the different terminology descriptions, the most common accepted competitive priorities or capabilities are cost, quality, delivery and flexibility (Li et al., 2008; Russell and Taylor, 2002). Among the competitive priorities there is a trade-off between competitive priorities at times, where the firm must choose the what competitive priority to pursue over the others, but it is purely based on the vision of the firm (Nurcahyo and Wibowo, 2015; Ward et al ,1996). Based on the descriptions of competitive priority as mentioned in (Butt, 2009) and the literature review done, a Table 4.2 has been provided for the firms to prioritize their core competencies.

Table 4. 2 Competitive priorities by various authors

Author	Competitive priority
Wheelright (1978)	Price, flexibility, quality and dependability
Avella et al (1998)	Cost, delivery, quality, flexibility
Hays and Schmenner (1978)	Price, quality, dependability, product flexibility, volume flexibility
Leong et al (1990)	Quality, delivery, cost, flexibility and innovativeness
Pun (2005)	Cost, quality, delivery, flexibility, innovation
Rasi et al (2015)	Cost, quality, delivery, flexibility

Adapted from Butt (2009)

Based on the literature study, the four main elements which help measure the manufacturing operational performance are cost, quality, delivery and flexibility. These are the generally agreed competitive priorities amongst researchers (Nurcahyo and Wibowo, 2015).

- **Cost:**

Low cost production is the well-established competitive priority in the manufacturing environment. Cost is the measure of the amount of resources that are used to produce a product (Hallgren, 2007). Cost leadership should focus on high profit margin based on competitive price of the product, in a way that it does not jeopardize the quality (Jones, 2014).

- **Quality:**

Quality forms the basis for all the other performance measures or dimensions, as It is the capability to make products with the specification mentioned by the consumer in a reliable and consistent way (Hallgren, 2007). This is the competitive priority that comes second in the list. It is with this competitive priority that a firm can attain excellence with products and selling the products at a competitive price (Jones, 2014). “Quality” refers to the way the firm produces the product with top quality, consistently (Rizvi, 2015).

- **Delivery:**

This competitive priority measures the product delivery speed, maintaining delivery due date. Delivery is integral part of operations and survivability of a firm (Butt, 2009). Product delivery is the time taken for the product to be delivered to the customer. On-time delivery of the product, faster delivery than the competitors, reduction in the lead time have been considered to measure the operational performance in the manufacturing environment (Rasi et al, 2015).

Table 4. 3 Competitive priorities description

Competitive priorities	Description
Quality	Manufacturing products with high quality and as per specifications
Delivery	Delivering product on-time, quicker than rivals
Cost	Low cost production without compromise on quality
Flexibility	Capable of producing variety of products in high volume

Adapted from Butt (2009)

- **Flexibility:**

"*Flexibility is the ability of a company to respond within penalty in terms of time, cost and customer's value*" (Rasi et al, 2015). Flexibility is the capability of a firm to reduce the waiting time between the production order and delivery. Flexibility is also considered as the capability to produce, in terms of customization, variety and volume. Organisations which are flexible provides the customers, various options to choose from variety of products and services in large volume, along with customization according to their requirements (Rizvi, 2015).

- **Dimensions of Competitive priorities:**

The Table 4.4 highlights the dimensions of the competitive priorities such as cost, quality, time and flexibility.

Table 4. 4 Dimensions of Competitive Priorities

Dimensions of price and cost:	Dimensions of quality:
• Manufacturing cost. • Value added. • Selling price. • Running cost - cost of keeping the product running. • Service cost - cost of servicing the product. • Profit.	• Performance - the primary operating characteristics. • Features - optional extras (the "bells" and "whistles"). • Reliability - likelihood of breakdown. • Conformance - conformance to specification. • Technical durability - length of time before the product becomes obsolete. • Serviceability - ease of service • Aesthetics - look, smell, feel, taste. • Perceived quality - reputation. • Value for money.
Dimensions of time:	**Dimensions of flexibility**
• Manufacturing lead time. • Due date performance. • Rate of product introduction. • Delivery lead time. • Frequency of delivery.	• Material quality - ability to cope with incoming materials of varying quality. • Output quality - ability to satisfy demand for products of varying quality. • New product - ability to cope with the introduction of new products. • Modification - ability to modify existing products. • Deliverability - ability to change delivery schedules. • Volume - ability to accept varying demand volumes. • Product mix - ability to cope with changes in the product mix. Resource mix - ability to cope with changes in the resource mix.

Adapted from Ifm.eng.cam.ac.uk (2019)

4.4 Trade off:

It is not possible for the companies to concentrate on all the competitive priorities at the same time. The firm must choose amongst the competitive priorities (cost, quality, delivery, flexibility), as it is necessary for firms to focus on certain aspects rather than focussing all. It can also sequence the competitive priorities where one would be employed after the another (Butt, 2009).

4.5 Discussion:

Kathuria (2000) have linked competitive priorities to performance, because a firm's competitive advantage is strengthened by increase in its organisational performance**.** Adel (2013) suggests that there exists a correspondence between the manufacturing competitive priorities and performance measures. Competitive priorities i.e., cost, quality, delivery and flexibility are critical operational dimensions in measuring operational performance (Rasi, 2015).

Competitive priorities belong to the first step in developing manufacturing strategy and they are the important variables for managers to decide and manage manufacturing operations (Si et al., 2010). Each manufacturer has different competitive priority, according to their own capability to compete and gain a competitive advantage over its rivals. Operational strategies should emphasize on competitive priorities to develop and maintain competitive advantage (Awwad et al., 2013). The following Fig 4.2 highlights the relationship between competitive priorities, manufacturing strategy, organisational performance and competitive advantage.

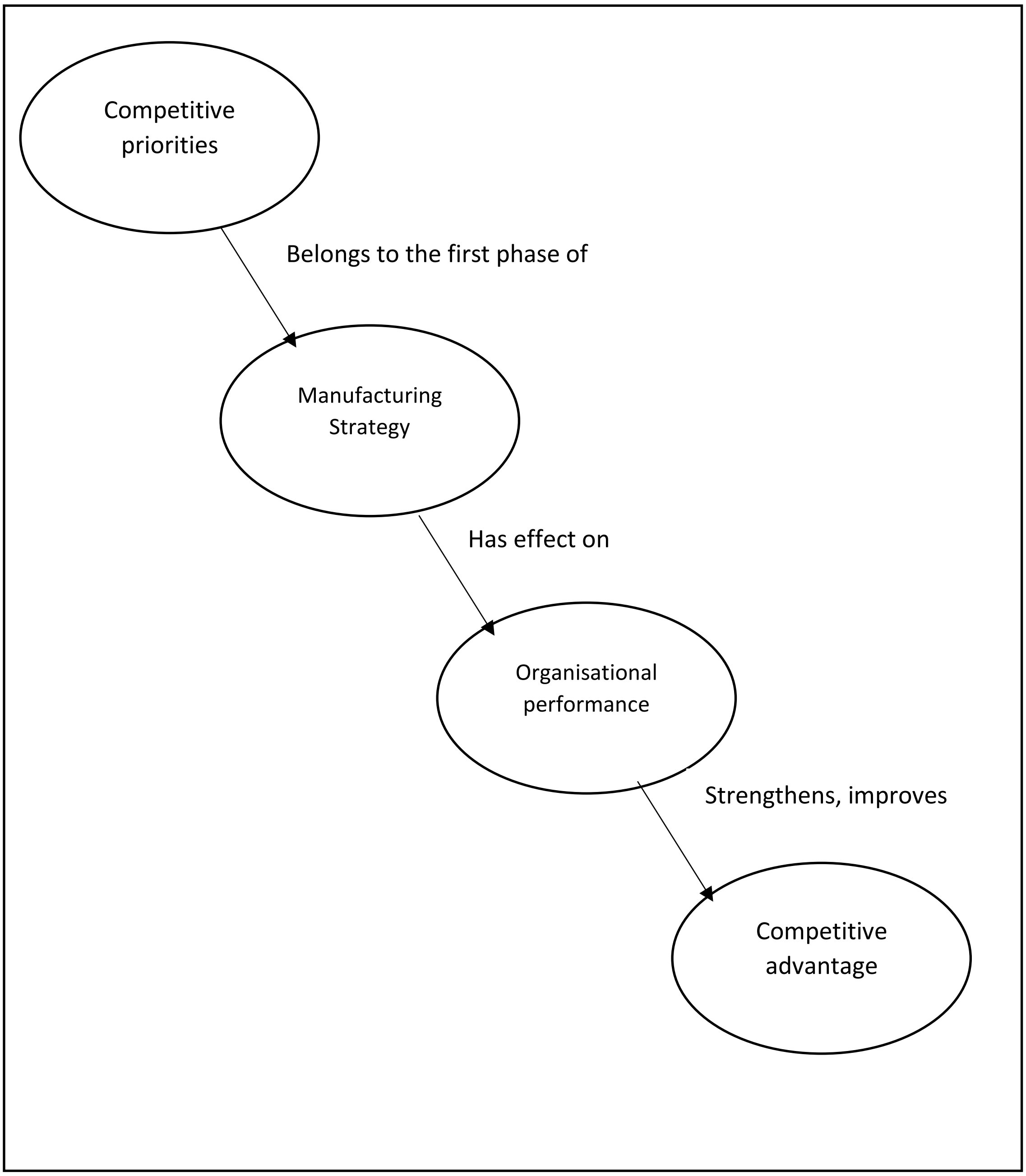

Fig 4. 2 Relationship between competitive priorities, manufacturing strategy, performance and competitive advantage

In the world of highly competitive, digitized, dynamic informatized, interconnected manufacturing environment, manufacturing firms, right from small SMEs to large-scale manufacturers need to adopt changes in their operational strategy by merging existing advanced manufacturing technologies and established computing technologies and be more innovative (Leong et al ,1990; Pun ,2004) to gain a competitive advantage. Innovation is the process of making changes either small or large to the business processes and services. Literature emphasises on innovations in process, product and technology for the firms to sustain competitive advantage. Innovation is considered as one of the "fundamental instruments of growth strategies" to increase the competitive advantage of the firm (Golightly et al., 2016). Due to the influence of IT, it is imperative for the manufacturing firms to adopt to a manufacturing setting where manufacturing processes are more distributed, diversified, shared among firms to achieve a collaborative, interactive, configurable manufacturing environment like cloud computing operating model which would provide the essential ability called rapid elasticity which would help the SMEs to scale up and down at a low cost rather than investing on proprietary assets on the shop floor. The concept of cloud computing, its advantages, the concept of elasticity and the cloud adoption issues are discussed the chapter 6.

Chapter 5
Analysis of Existing Manufacturing Technologies

5.1 Introduction

Some of the existing manufacturing models that make great contribution to the development of manufacturing information would include Application Service Provider, Lean Manufacturing, Agile Manufacturing, Networked Manufacturing and Manufacturing Grid.

5.2 Application Service Provider (ASP)

Application Service Providers are companies that host software, maintain the infrastructure necessary for the client organisation and provide them access through an internet browser. ERP (Enterprise Resource Planning), MES (Manufacturing Execution Systems) are popularly known applications provided by the ASPs. The attractions of ASP value proposition include the following:

- Confirms and maintains the specific requirements of an organization without huge burden on its infrastructure.
- Flexibility to reconfigure on demand.

As a result of the technology craze in 2000s, telecommunications market demand grew faster than supply and outsourcing of manufacturing drove the need for "remote viewing" to ensure to plan and order fulfilment. But ASP failed when the market started to decline (Steidinger, 2011). ASPs include offer local area networking capabilities which are offered off premises. Examples of some of the more well-known ASPs include Qwest, SAP and Hewlett-Packard.

5.3 Lean Manufacturing

Lean Manufacturing identifies and eliminates waste and reduces variation, which is considered as the best manufacturing practice (Bhuiyan and Baghel, 2005). Lean manufacturing has helped to lower operating costs by cutting down waste at every stage of a manufacturing process. By combining Lean principles along with Kaizen (continuous improvement), businesses become competitive because the removal of unnecessary activities and variations through continuous improvement. But these practices would create issues when two different firms integrate, and the externally imposed quality management standards conflict (Peter et al, 2011).

5.4 Agile Manufacturing

Agile manufacturing is a method of manufacturing which combines an organization, people and technology into an integrated and coordinated whole. Agile manufacturing is seen as the next step after Lean Manufacturing in the evolution of production methodology (Bala, 2012). Agile enables manufacturers to develop the best consumer-oriented product and manage the varying demand simultaneously (agilemanufacturing.weebly.com, n.d.). Agile manufacturing helps the organizations to face the intensifying global competition. But firms would suffer if there is a high demand for volume and variety simultaneously and the products are wasted when the demand goes down during a high production rate, thus being unable to adapt to changes on demand. Also, the maintenance cost of complex machineries is very expensive and would add to the cost when there is a breakdown, increasing the production downtime.

5.5 Networked Manufacturing

Networked manufacturing is a manufacturing model, which is in accordance with the idea of agile manufacturing. It uses internet technology to establish a flexible, effective, dynamic and mutually beneficial business alliance. It allows the reorganization of resources such as research, design, production and marketing, thereby enhancing quick response to market and competitiveness of the enterprises (Xuefang et al, 2010). Networked manufacturing is a distributed manufacturing paradigm that coordinates networked resources to achieve a common manufacturing objective which cannot compose resources to satisfy dynamical networked manufacturing activities on demand.

5.6 Manufacturing Grid (MGrid)

"MGrid is a manufacturing-oriented virtual network on the basis of internet, grid, and other related technologies" (Fan, 2004). Manufacturing Grid (MGrid) organises enterprises, organizations and all kinds of resources which may be geographically distributed (Tao et al., 2011). This allows the users to conveniently utilize all the resources remotely located in distributed heterogeneous systems in a transparent way. The main goal of MGrid is to share and use the distributed manufacturing resources and services in a smooth manner without disruptions.

However, the resources of MGrid are far more diverse and complex than those of Grid Computing. There is not a standard unified format for addressing the manufacturing resources and services. There exists a lack of relationships and semantics and manufacturing service composition which makes MGrid a complex and challenging system to adopt (Zhang et al, 2008).

5.7 Limitations of existing manufacturing technologies

Wang (2012) states that the above-mentioned manufacturing models have contributed much to the development of manufacturing, but are unable to deal with the strategic, long-term barriers that hinder the achievement of efficient manufacturing process in a highly complex and dynamic networked manufacturing environment, which is quite evident in the following points.

- The above-mentioned manufacturing modes are much concerned about how to gather the resources to be the used readily rather than knowing better advantageous resources and services (Tao et al., 2011)
- There is lack of management mechanism specifically for networked manufacturing resources, where the resources are essentially application specific and thus the concept of reusability of the resources becomes difficult (Xiong. et.al 2008).

5.8 Impact of Cloud in manufacturing business processes

Cloud computing is a business model which delivers applications, platform and infrastructure as services to the consumers. The consumers can easily access the software or services via the internet with low or no cost using any type of device ranging from PC to mobile handheld devices. Cloud has the inherent capability of dynamically scaling up and down as demand changes and this has a positive influence on the service cost. With loads of advantages cloud computing has already began to impact manufacturing business processes. But the impact is only on the IT section of manufacturing industry. Providing software services (SaaS – Software as a Service), for the organisations so that the upfront cost, upgrade cost, maintenance cost of application software can all be taken care by the cloud service provider. Cloud also provides platform (PaaS – Platform as a Service) for manufacturing firms to develop proprietary software for their customized access. It provides storage, server access by providing IaaS (Infrastructure as a Service). Cloud computing has become a major enabler for the manufacturing industry that can transform the traditional business model, by helping with product innovation with business strategy and create effective networking for collaboration. Adoption of cloud computing technology in supply chains of manufacturing industry will also improve performance in the form of better information visibility, cost reduction, and improved agility (Ali, 2013).

5.9 The need for Cloud in manufacturing environment

As one of the most expectative trend and new evolution for Information Communication Technology (ICT) in the 21th century, cloud computing, which has gained significant attention in recent years (Mell & Grancs ,2011), is not only changing the computing paradigm, but also the style of computing where dynamically scalable and virtualized resources is provided as services over the internet. It introduces tremendous opportunities, as well as, challenges. Cloud computing lowers the upfront cost for the small and medium enterprises. SMEs can gain from the computing power for a relatively short time, and also as and when needed.

Cost of capital in hardware and software infrastructure could provide SMEs with the new opportunities to acquire IT capabilities that were not feasible in the past (Ali, 2013; Xu, 2012). Also, DAMA (Design Anywhere Manufacture Anywhere) demands the exchange of data across multiple sites, which implies that it is also believed that cloud computing may play a crucial role in adopting DAMA philosophy (Xu, 2012). Cloud computing operating model enables data sharing (Golightly et al., 2013). This makes the cloud adoption vital in manufacturing as it becomes more globalized, distributed and demands the firms to be agile. There are two different ways of adopting cloud in manufacturing. One is the adoption of cloud computing on the IT section of manufacturing, which leads to gaining services like SaaS (Software as a Service), PaaS (Platform as a Service), and computing IaaS (Infrastructure as a Service). Another one is adopting cloud operating model in manufacturing, i.e., providing manufacturing as a service, thus making manufacturing as a utility. This is similar to the concept – "computing as a utility". Manufacturing firms can get manufacturing resources as services from a third-party service provider. This concept of collaborative, networked manufacturing mode would enable a flexible and adaptive infrastructure for firms to share and use manufacturing resources and services on-demand in a highly dynamic large-scale business environment (Wang et al., 2012). This would enable SMEs to make products with low-cost and high-quality and gain a competitive advantage and sustain in the complex manufacturing environment.

5.10 Agility in manufacturing organizations

Agility in manufacturing business is in big demand particularly in SMEs. Agility for many organizations means reacting swiftly to a changing business environment. This is jumping from one task to the next, change requirements, being able to change, cope and adapt to an ever-moving target. Cloud computing has been widely known to be associated with capital costs, resource availability, reliability, scalability and elasticity there by benefitting the enterprise to be more agile by meeting the fluctuating demand (Wang et al, 2012).

It is evident that cloud computing is cost effective due to its agile distribution of the resources (Lin and Chen, 2012). Manufacturing SMEs will be able to utilize these capabilities of cloud computing which includes lowered capital investment regarding infrastructure and elastic capability to scale out their resources in a widely networked service-oriented manufacturing environment. Elasticity enables the manufacturing SMEs to be flexible by scaling up the resources when the demand is high and scaling down the resources when the demand is low. Elasticity enables SMEs to stretch their resources and bounce back to its original capacity as and when the workload changes. This capability enables manufacturing SMEs to be flexible and agile in an ever-demanding manufacturing environment. Though not completely, elastic capability is in a way new to manufacturing as it is the unique capability of cloud computing which enables the firms to scale-out the resources when the demand is high and scale-in when the demand is low, and by a third-party service provider who manages all the issues and challenges that would arise when using this paradigm.

PART IV- CLOUD BASED ELASTIC MANUFACTURING

Chapter 6
Cloud Computing

6.1 Introduction

Before we explore and analyse the challenges, issues and feasibility of cloud-based manufacturing, it is imperative to understand what cloud computing is, what are its characteristics and what has made the IT industry to adopt this technology in a short span of time.

6.2 What is cloud computing?

There are several definitions for cloud computing by various authors. Cloud computing can be used as a metaphor for internet. Cloud computing acts as a construct where applications can be accessed from distant locations other than the user's computer (or any other device). Most likely this distant location seems to be a distant data centre (Velte et al, 2010). It is similar to the internet access, where anyone can access their email, any time from any device with their credentials, as long as the device is connected to the internet. The user does not bother about where the email server is, rather the user gets the service that the user wants on pay per use basis. The user pays for the data that has been used to access the internet. This concept transforms computing as a utility (Shroff, 2010; Dong et al., 2010).

In the concept of cloud computing, where the resources are pooled, partitioned and provisioned as per the requirement, the communications are based on a set of standards

(Sosinsky, 2011). Internet has most of the characteristics similar to that of cloud computing, like abstraction, protocols and standards. The concept where a user, when requesting for computing services, is provisioned with the same, on demand, from a heterogeneous and autonomous computing resources, that are projected as a whole, from the external may be called as cloud computing

Though there are claims that there is no fixed definition for cloud computing, NIST (National Institute of Standards and Technology) defines what cloud computing is and specifies important characteristics of cloud computing.

> The U.S. National Institute of Standards and Technology (NIST) defines cloud computing as *"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction."* -(Mell and Grancs, 2011).

6.3 Characteristics of Cloud computing

The cloud computing model possesses characteristics that can be considered as advantages for adopting cloud based operational model. These characteristics form the foundation for a consumer to validate if the adoption of cloud computing in their firm would add value than their legacy business model. The Fig 6.1 briefs the essential characteristics of cloud computing model, along the five characteristics that are released by NIST (Mell and Grancs, 2011).

- **On-demand Self-service:**

  A consumer can be provisioned with computing capabilities as soon as or whenever needed automatically from the service provider without the intervention of any middle man.

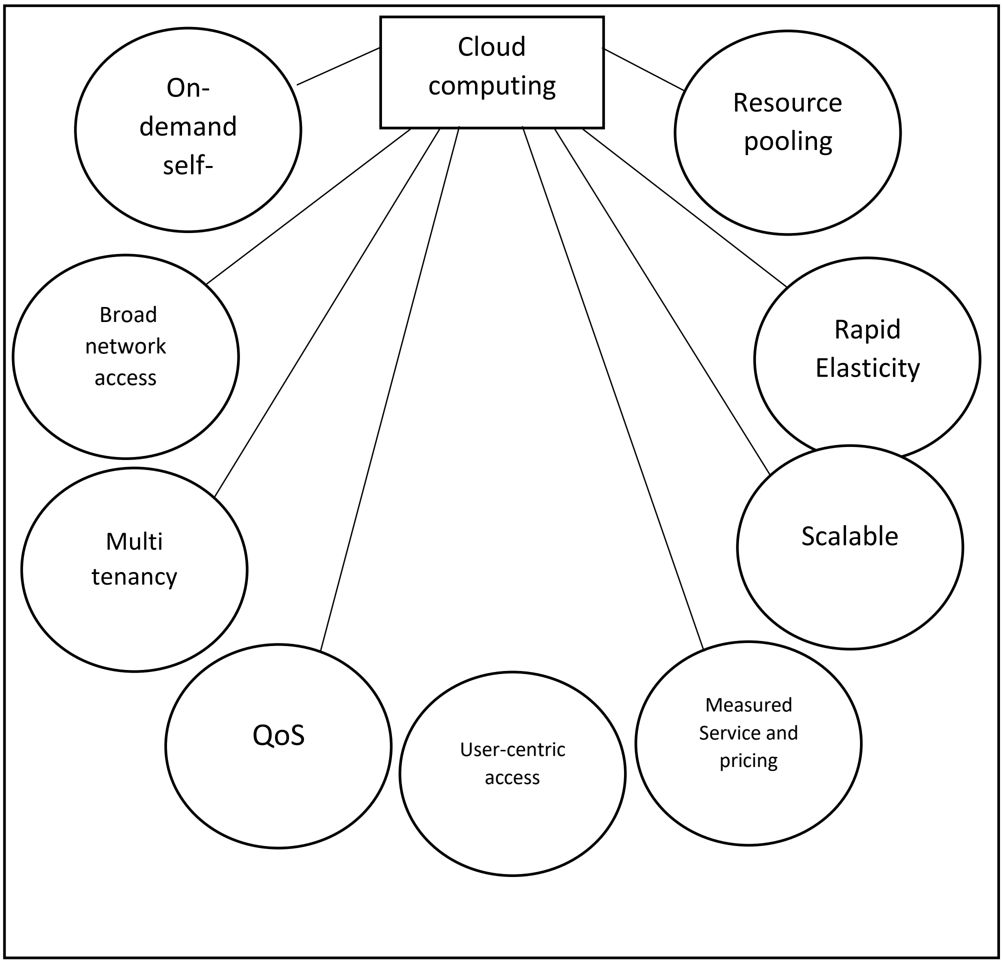

Fig 6. 1 Characteristics of Cloud computing

- **Broad network access:**

Computing capabilities can be accessed on-demand over the wide network (internet), without the intervention of middleman. Capability access can be done either through thick or thin clients i.e., hand-held devices like mobile phones, tablets…provided they are connected to the internet.

- **Resource pooling:**

Computing capabilities are pooled together as a cloud for the consumers to access them, in the notion that services are provided on-demand from one location. This resource pooling allows multiple consumers to access the resources that is either physical or virtual, such as software, storage, memory, network bandwidth, etc.

- **Rapid elasticity:**

Consumers will be provided with the capabilities on-demand, as and when needed only, which means the services are provisioned and released to the consumer in an elastic manner.

- **Measured service:**

Consumers will be charged only for the services utilized by them on-demand, on pay-per use basis. Services consumed by the user will be monitored and measured by the service provider which makes the communication, transaction and billing quite transparent between the user and the provider.

- **Scalability:**

The computing resources are scalable over several data centres (Furht and Escalante, 2010)

- **User-centred design interface:**

The cloud computing services are accessible by the consumers through any interface, via any device, from any location, as long as they are connected to the internet.

6.4 Service models

Mell and Grancs (2011) defines three basic types of service models under the concept of cloud computing. Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and

Software as a Service (SaaS). Computing capabilities are provided to the consumers in three basic types of service models in the concept of cloud computing. Fig 6.2 highlights the service models in cloud computing.

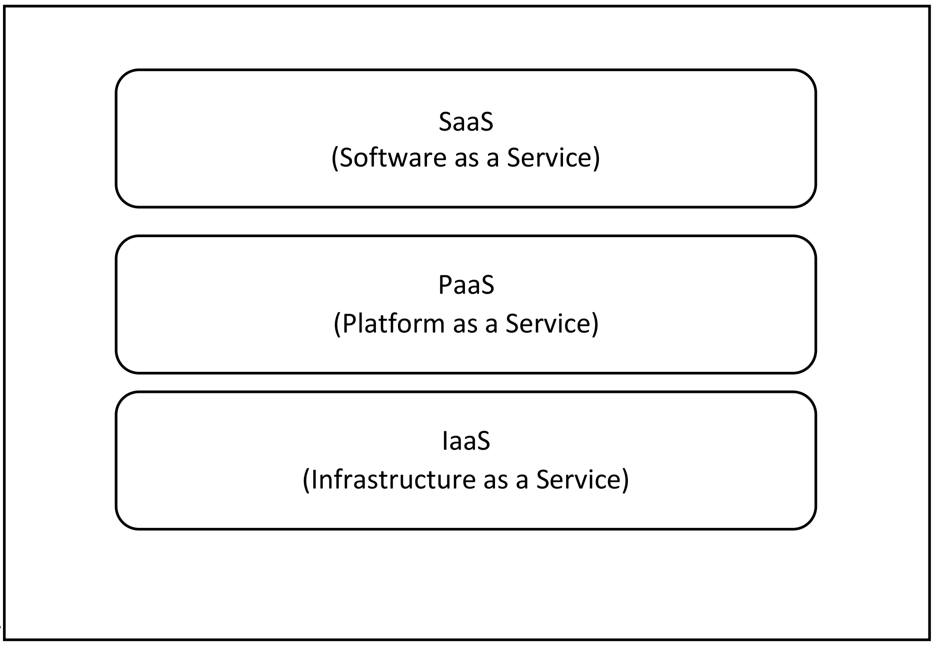

Fig 6. 2 Cloud service models

6.4. 1 Software as a Service (SaaS)

This service model enables the consumer to access the applications that run on the underlying cloud infrastructure. The consumer can access the applications from various devices (personal computers, mobiles, tablets, etc..) through thin client interface like web browser. The customer does not have any control over the underlying cloud infrastructure, except for the limited access to configuration settings for user-specific applications (Mell and Grancs, 2011). Applications are hosted as service to consumers, who can access them through the internet. Since the software is hosted off-site, the consumer does not have to take the hassle of maintaining it. Upgrading and maintenance of the software becomes the responsibility of the service provider. The consumer will be charged based on the usage of the application (Velte et al., 2010).

The most common and familiar example of Software-as-a-Service is the e-mail access through the web browser. The on-demand application access in SaaS saves the time and hassle of installing the software in the consumer's PC (Williams, 2010).

The firms can add as many as users as they want to access a software and will be charged on a pay-per-use business model. Enterprises of all sizes are adopting SaaS as an alternative to on-premise deployments of software and hardware (Vladimirskiy, 2016).

Since SaaS allows enterprises of any size to buy rare and expensive software without large up-front cost investment, with increased flexibility, faster upgrades and scalability, enterprises are making the switch to this service model (computer economics, 2019). It helps the firms to concentrate more on their core competencies than struggling with software related issues.

Some of the examples of SaaS include Salesforce, google apps, Amazon Web Services, Dropbox, Slack and fully functional applications like CRM, ERP and so on. SaaS allows multiple users to access the services at any point of time, which leads to a shared data model called Multi-tenancy model (Sosinsky, 2011).

6.4. 2 Platform as a Service (PaaS)

This service model lets the consumers to develop and deploy applications that can be created using the programming languages, libraries, services and tools that are available on the platform of cloud service provider, through PaaS (Mell and Grancs, 2011). It provides a browser-based development environment and tools to create applications that can run in SaaS model (Sosinsky, 2011). PaaS provides tools to design webforms, define business rules and create workflows. This service is more beneficial for enterprises who have their own software development team and aim to use cloud service model for application development and hosting (Williams, 2010). In other words, PaaS is an application delivery model that provides all the resources required to develop applications and services, completely over the internet without installing or downloading the required software (Sosinsky, 2011; Velte, et al., 2010).

PaaS enables collaboration as it allows multiple users to access and work on the same project (Sosinsky, 2011). PaaS enables scalability, concurrency management, multi-tenant capability, failover, security, quick integration with other applications that belong to the same platform, unite geographically distributed development teams to work together (Velte, et al., 2010; Williams, 2010; Azure.microsoft.com, 2019). The consumer or the developer does not have control over the underlying cloud infrastructure which includes the servers, networks, operating systems or storage except for the configuration settings of the environment to host applications (Mell and Grancs, 2011). PaaS adds middleware, integration features to the IaaS model (Sosinsky, 2011).

6.4. 3 Infrastructure as a Service (IaaS)

This service model offers the consumers, the capability to access the fundamental computing resources such as processing power, storage and networks through web

(Mell and Grancs, 2011). Linthicum (2010) defines Infrastructure as a Service, as Data centre as a Service, as it lets the consumer to lease the physical server that belongs to the cloud service provider.

The number of resources to be used can be modified as per the demand by the consumer. The consumer is charged only for the resources that has been used and anything extra. The management and the maintenance of the infrastructure resources is the responsibility of the cloud service provider (Dataflair team, 2019). IaaS makes it easier for the consumers to rent a data centre environment without the hassle of developing one and maintaining the same data centre footprint in their own premises (Hugos and Hulitzky, 2011). The consumer does not have control over the underlying cloud infrastructure, rather they can specify, when the infrastructure resources can be requested and released (Hwang et al., 2012).

Organisations which conduct research-oriented projects would be benefited more from adopting IaaS, as it enables them the scientific and medical researchers to test, analyse at levels that is not feasible without access to additional computing resources. It enables small and medium enterprises to scale their resources when there is a higher demand, without having to pay for the capital expenditure for the maximum number of resources (Hurwitz et al., 2010).

6.5 Deployment models

Deployment models are different types of cloud computing. The cloud service models are deployed in different ways, based on the consumer's preference. Mell and Grancs (2011) defines four types of these deployment models in cloud computing. They are Public cloud, Private cloud, Hybrid cloud and Community cloud. These are the principal cloud service delivery models, which enables the cloud service provider to provision scalable IT resources like CPU or storage or software development environment or software applications (Furht and Escalante, 2010). The service models help the consumer to decide what type of service they need, whereas deployment models help the consumer to know the location and the purpose of the cloud (Sosinsky, 2011). Though all the three deployment models offer similar benefits like cost-efficiency, performance, scalability and reliability, it is up to the consumer to choose the deployment model based on their business needs (Azure.microsoft.com, 2019).

6.5. 1 Public cloud

This is the first deployment model that gained the attention of IT for its ease of usage, availability, scalability and reliability. This public cloud infrastructure is generally provisioned by either a business or an academic or a government organisation to the general public or a large industry group (Linthicum, 2010).

Since this public cloud is owned, managed and operated by a third-party cloud service provider, the infrastructure exists on the premises of the provider (Mell and Grancs, 2011). The service provided in this type of cloud is described as a "utility", because the consumers use the service on a pay-as-you-go model (Sosinsky, 2011). Public cloud is also called as external cloud, as the third-party service provider who is off-site, dynamically provision the computing resources to the consumer through web services (Xing and Zhang, 2012). The resources in this public cloud are shared by the consumers, where the maintenance of the infrastructure is the responsibility of the provider. Deployment of public cloud is much quicker than on-premises infrastructure and it is infinitely scalable as it can collaborate higher level of resources.

Public cloud allows multi-tenancy because employees from an enterprise can access the same resource (application, storage, server…) from any branch distributed in different geographical locations, using any device, with the only requirement of being connected to the internet. It is cost-effective as it charges the consumers on a pay-as-you-use basis (Dataflair team,2018).

With efficient security methods being implemented, and effectively managed, the public cloud could be as secure as possible, like a private cloud (Azure.microsoft.com, 2019). This deployment model is best suited for globally distributed teams of an enterprise, as public cloud enables them to easily access the centrally managed infrastructure with a connection to the internet (Shroff ,2010).

6.5. 2 Private cloud

This deployment model is best suited for a single organization, where the cloud can be owned, managed and operated by the organization itself or in combination with a third party. The private cloud can be on the premises or off the premises (Mell and Grancs, 2011). In the private cloud the data is under the control of the single entity, for example CaaS (Compliance as a Service) system is built in a private cloud, where the data is under the control of the entity, including the transactions being monitored (Sosinsky, 2011).

Private cloud enables an individual organisation to maximize the usage of its computing resources and be more flexible and responsive to the company needs, which is not feasible in the legacy IT operating model (Hugos and Hulitzky, 2011).

Firms can build their private cloud data centre in their heterogeneous corporate environment, according to their business needs to leverage existing IT infrastructure and use them in a more cost-effective way. The private cloud eliminates issues like data security, regulatory compliance issues that would arise in a public cloud.

Private cloud would best suit the companies like health care firms, which handle sensitive data that are not be shared in the public platform. Private cloud allows the firms to try and test the reliability of the cloud adoption in a private mode and then move onto the public cloud infrastructure in the future to save the cost. Private cloud may suit the firms which has proprietary applications that cannot be used in a shared platform, outside their own or their sister concerns which are geographically apart (Leapfrog IT Services, 2019). The hassles involving Service Level Agreement (SLA), data security, regulatory compliance could be eliminated in private cloud, as they are located on-premises of the consumer (Hugos and Hulitzky, 2011).

6.5. 3 Community cloud

Community cloud can be thought of as a public cloud, with the level of privacy, security and regulatory compliance similar to that of a private cloud (Kleyman, 2014). This deployment model is provisioned for an exclusive usage by consumers that belong to a community from firms with same concerns, mission, security requirement, policy and compliance considerations. Community cloud may be owned, managed, operated by a third-party cloud service provider either on their own or in combination with one or more of the firms in the community. This deployment model can be implemented on-premises or off-premises (Mell and Grancs, 2011).

Community cloud would suit the group of organizations that have same security concerns. Though these communities may be benefited more from adopting public cloud deployment model, they will have less worry about the neighbour with whom they are sharing the resources in the community cloud, as the firms that belong to the same community know each other (Williams, 2010).

6.5. 4 Hybrid cloud

This deployment model blends the characteristics of both public and private cloud. The cloud services are provided in public and private mode as per the need of the consumer. The consumer might choose to hold the sensitive data in the private cloud and gain access to common applications, storage from the public cloud, which is cost effective than private cloud (Furht and Escalante, 2010).

For example, an organisation can use the public cloud as an overflow for the private cloud, where less-critical workloads can be moved to off-premise public cloud dynamically to manage unpredictable load demands. A hybrid cloud may combine multiple clouds like public, private and community where the unique identities of the clouds are retained in spite of being bound together. A hybrid cloud can provide proprietary or regular standardized access to the resources along with portability (Mell and Grancs, 2011).

6.6 Concepts in cloud computing

There are two essential characteristics of cloud computing: Abstraction and virtualization. In a cloud computing model, applications are required to run on specific operating system and compatible hardware platform with a certain type and amount of storage and drivers. But the consumer requesting the application as a service, need not know these complex dependencies, rather they would just access the application they need. The requirements to run the software application is encapsulated like a capsule and provided as a service to the user. The user is abstracted from the hardware, networks, infrastructure and storage. These are the main critical concepts that make the cloud computing unique from other technologies (Rushfinn, 2011).

6.6. 1 Abstraction

The rationale behind the shape of cloud drawn as a representation of internet is in fact the concept of cloud computing called abstraction. As mentioned in the SaaS, PaaS, the consumers are provisioned with the services like software applications, IDEs that run on physical systems, whose whereabouts (location, storage, outsourced administration) are not known to the consumer requesting the services, rather the consumers would receive the ubiquitous services (Sosinsky, 2011). The capability of abstraction is one of the unique characteristics of cloud computing that has made the concept to stand out. Abstraction helps the consumers to realise the full capability of cloud computing, i.e., resource sharing and ubiquitous access.

6.6. 2 Virtualization

Virtualization is the concept that enables scalability in cloud computing. Creating virtual versions of computing resources like hardware architecture, operating system, storage and networks in order to achieve scalability, is called virtualization (J and S, 2016). Multiple instances of virtual machines run on a single machine but gives an illusion to the consumer that he is accessing independent machines. This concept of hiding the virtual existence of machines is abstraction. Because of this illusion of infinite computing resources that are available on demand, it eliminates the need for the users to plan well ahead and it helps them face the unpredictable rise on workload. This concept of virtualization simplifies IT operations, increases high availability of applications, help achieve scalability, respond quickly to the unpredictable business demands, makes greenhouse gas reduction a possibility (J and S, 2016)

.

6.7 Why cloud?

Despite having essential characteristics and reasons to adopt cloud computing, there are several other features that (Sosinsky, 2011) highlights that have been attractive enough for industries other than IT to adopt cloud computing.

Lowered costs: Significant reduction in cost is often encountered as the efficiency of the operations in the cloud network are high.

Quality of Service: There is an agreement called SLA (Service Level Agreement) between the service provider and the consumer for the service to be provided with high quality no matter what obstacles occur, the service has to be offered smoothly to the consumer at any cost.

Lessened barrier to Entry: New and budding SMEs may be benefited by this characteristic of cloud computing as the SMEs can save cost of capital. The capital expenditures are greatly reduced in cloud computing which enables any firm to become a business giant in no time because of this capability

Reliability: Since there is a scale of network of organisations that are involved to achieve a single process, the reliability factor increases, along with the capability to provide load balancing and failover.

Ease of utilization: Pre-requirements to access the services provided by the cloud service provider is not needed when requesting for a service, including hardware or software licences.

These are the essential characteristics of cloud computing that makes it inescapable for industries to adopt cloud computing.

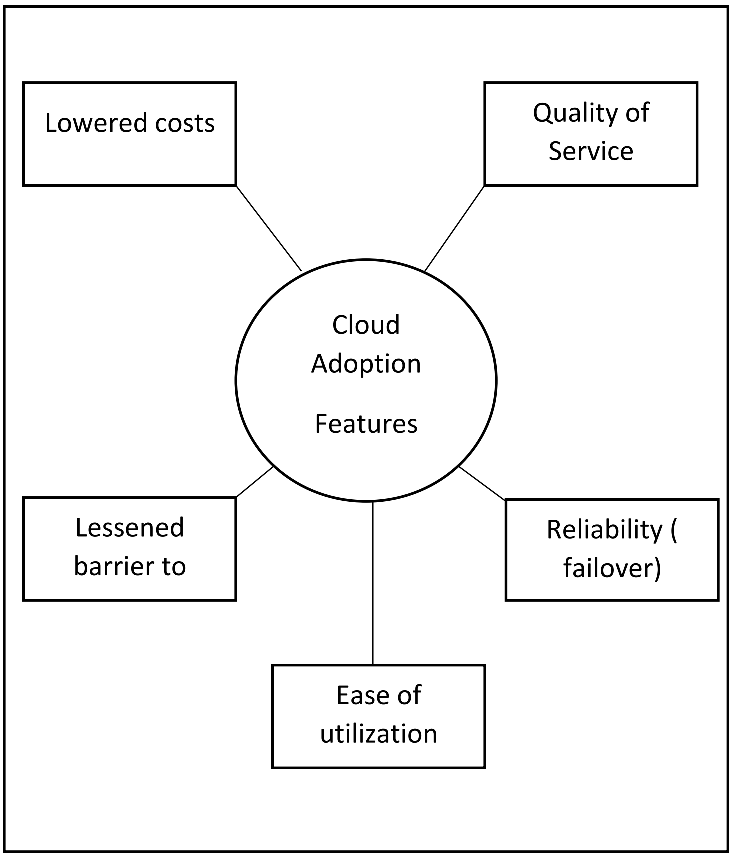

Fig 6. 3 Cloud Adoption features

6.8 Cloud adoption in manufacturing

"*Developers are continuously trying to integrate cloud technology into business in numerous ways which can ultimately result in benefitting business activities. People having "cloud on their mind" have been lured by the vast promise associated with cloud computing*" (Newgenapps.com, 2018).

"*Cloud computing has clearly become a driving force in the information technology world. Over 90% of global enterprises report using cloud as part of their business. With over $33 billion in projected 2015 spend, cloud is now the largest category in IT infrastructure budgets*" (vmware.com, 2015).

Adoption of cloud in the field of manufacturing is very small and only 7% of the respondents of a survey conducted by The Economist Intelligence Unit, believe that cloud computing will make any pervasive pressure in the manufacturing industry (Eiuperspectives.economist.com, n.d.). Manufacturing industry is lagging behind banking and retailing industry in the adoption of cloud computing. The main obstacle to realise the adoption of cloud in manufacturing is because of the challenges involving physical resources, which involves sensors, IoT, standardization of communication protocol amongst machineries unlike IT, or health care or retail industries where adoption of cloud is just a matter of coding. Predicting the importance of cloud in the field of manufacturing is highlighted below in the following quote.

"A *modern television is built from 2,000 components, a car from 30,000 and an Airbus A380 from over 4 million. These raw materials and parts must flow in from thousands fo locations to arrive across the globe on-time, on-spec and in-budget. This complex chain requires huge scalability, access by multiple devices with different operating systems and the ability to manage large pools of data, all done cost-effectively – it is difficult to imagine building this outside of a cloud network*" (Eiuperspectives.economist.com, n.d.).

Rationale for the adoption of cloud computing in manufacturing SME is multi-fold, which includes the benefits of reduction of cost, scalability improvement, efficient resource utilization. As SME is apparently different from large manufacturers, especially on the perspective of resource constraints, adoption of cloud is expected to facilitate a significant reduction of financial burden, that which are associated with adoption of a new technology (Carcary et al., 2014).

Cloud-computing applications is expected to impact virtually every aspect of modern manufacturing companies. ... In particular, cloud computing facilitates research, design, and development of new products, which powers innovation, reduces product development costs, and speeds time to market.

6.9 Conclusion

As highlighted in this chapter, it has become imperative for manufacturing SMEs to adopt cloud computing to improve its manufacturing performance and there by gain a competitive advantage. This research focuses on adopting cloud operating model in manufacturing rather than adopting cloud on the IT sector of manufacturing. Cloud computing operating model is a service-oriented operating model, where IT tasks are serviced to the consumers requesting for it. Adoption of cloud operating model in manufacturing is similar to what has been going on in IT sector. Cloud computing in IT sector changes the way industries and enterprises do their businesses in that dynamically scalable and virtualized resources are provided as a service over the Internet. In cloud manufacturing, distributed resources are encapsulated into cloud services and managed in a centralized way (Xu. 2012). Cloud based manufacturing model is similar to that of cloud computing operating model where the computing resources, especially the hardware is replaced with manufacturing resources including machineries (Wang et al.,2012). The next chapter elaborates the cloud based operating model in manufacturing with an essential characteristic called "Elasticity" or "Rapid Elasticity".

Chapter 7
Cloud based Elastic Manufacturing Model

7.1 Introduction:

In the process of solving manufacturing problems such as inefficient resource utilization, inability of the manufacturing SMEs to start up a firm due to high capital cost, maintenance cost, unable to meet the unpredictable demand in the market due to the lack of scaling out, loss of opportunity due to less elasticity, poor agile manufacturing system. and lack of innovative technologies. Advanced technologies like cloud computing and IoT are combined to introduce a new networked manufacturing mode called cloud-based manufacturing. This new networked manufacturing mode is based mainly on cloud computing operating model and service-oriented architecture.

The cloud-based manufacturing is expected to promote the manufacturing business into a new level of networked, knowledge based, intelligent, service-oriented manufacturing mode. The implementation of manufacturing as a service is still in a conceptual level, though this concept has attracted great attention of industry and academia. The objective of cloud-based manufacturing is to pool all the physical manufacturing resources and present them as a service whenever there is a request for one. This is a new and unique way to provide manufacturing resources. Sometimes the cloud service provider may just do the brokerage services between the manufacturing resources and the consumers.

7.2 Definition

Cloud manufacturing has been defined as ubiquitous, on-demand, service-oriented, knowledge-based, intelligent, networked, collaborative, interoperable, distributed manufacturing execution model. It is proposed as a new manufacturing mode which incorporates cloud computing, IOT, agile manufacturing, networked manufacturing, manufacturing grid and virtualized manufacturing and other advanced manufacturing technologies (Lu et al, 2012; Qanbari, 2014; Wang et al, 2012; Yongxiang et al, 2013; Zhang et al, 2014).

7.3 Service models:

On the cloud, similar to basic cloud computing service models (IaaS, PaaS, SaaS), now "Anything as a Service" is feasible in almost all the industries, be it manufacturing or IT or health care or so on. This "Anything as a Service" is represented as "XaaS" (Fedoseenko, 2018). Few examples of "XaaS" in manufacturing may include,

- Manufacturing Software as a Service
- Computing Platform as a Service
- Computing Infrastructure as a Service
- Manufacturing Design as a Service
- Logistics, Delivery as a Service
- Raw Material as a Service
- Manufacturing as a Service

This research focuses on a service model where "Manufacturing is provided as a utility", called "Manufacturing as a service". Based on the cloud computing delivery models and previously proposed cloud-based manufacturing models (Ning et al, 2011, Wu et al, 2015, Wang et al, 2012), a networked, cloud based elastic manufacturing conceptual model has been proposed which emphasises on elasticity and embeds an elastic assessment tool.

The cloud computing service delivery models possess key characteristics such as resource pooling, rapid elasticity and measured service. The elastic capability is the key characteristic that would address the major issues of manufacturing SMEs, such as loss of opportunity, poor agility, inefficient resource utilization and resource idleness. The manufacturing model that is proposed would help manufacturing SMEs to realise the elastic capability of cloud operational model and thereby improve its manufacturing performance.

7.4 Operating principle:

The operating principle of cloud-based manufacturing model is shown in Fig 7.1. A manufacturing service is requested by the manufacturing SME. The SME requests for a service from the cloud service provider through the cloud manufacturing platform. The cloud service provider processes the request by accessing the knowledge

base for the availability of the capabilities and resources and responds by a service package. Cloud service provider provides a platform and acts more like a broker who manages a huge network of manufacturing resources and capabilities behind the cloud. These available manufacturing resources are hidden from the end user (consumer). The consumer does not know where the resources are, in terms of geographical location and whereabouts.

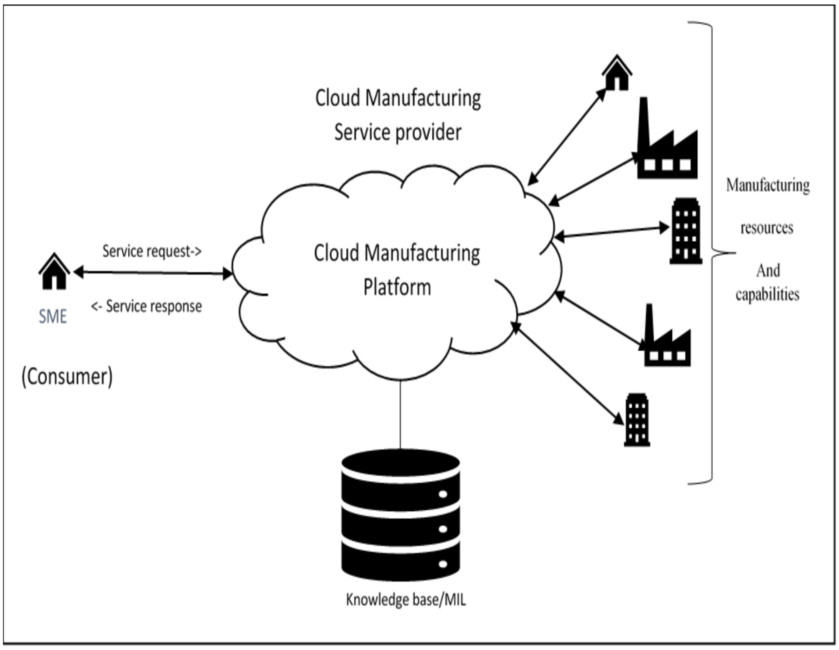

Fig 7. 1 Operating principle of Cloud based Elastic Manufacturing Model

The consumer will have an illusion of receiving the service from single location. The manufacturing resources are virtualized, bundled up and given as a package. Thus, this manufacturing platform is proposed to implement the cloud computing operating principle exploiting its key concepts of virtualization, encapsulation and abstraction.

7.5 Analysis of architectures of cloud-based manufacturing model

There are several architectures with different numbers of layers that have been proposed for cloud-based manufacturing operating model. Every author when proposing a new concept or technique in the implementation of cloud manufacturing, proposes different set of layers in the cloud manufacturing architecture. In this chapter, the author compares, and analyses various cloud manufacturing architectures that have been previously proposed and discusses the rationale of the layers added or taken off from the basic cloud manufacturing architecture.

The Table 7.1 summarizes the architectures proposed by different authors for the cloud-based manufacturing model. This table includes at the least 12 architectures that have been proposed.

The architectures differ from each other on the context of the number of layers other than the basic interface layer, middle layer and the manufacturing resource layer. Each author has either included or excluded layers from the architecture that was proposed by Ning et al. (2011).

An architecture for cloud manufacturing was proposed by Bohu et al (2010) which has five layers (user layer, application layer, service layer, virtualized resource layer, physical layer). All the other proposals are most likely based on this model. All the architectures involve three main actors, i.e., consumer (user), cloud service provider and the manufacturing resources (physical, virtual, data and information).

In general, a cloud manufacturing architecture would include, a layer for the user to interact with the middle man and a layer for the manufacturing resources to interact with the middle man and a layer which acts as a middle man (cloud service provider) for the linking, matching, maintenance, billing and all other services. Every other author has either included a layer or taken off a layer whichever they think is feasible for achieving cloud-based manufacturing, using different methodologies.

User layer/User interface layer / Application layer/Portal layer:

Usually the first layer is the interface layer through which the consumer requests a manufacturing service. Some of the authors have mentioned the first layer as User layer (Bohu et al, 2010), some as Interface layer (Wang et al., 2012, Adamson et al., 2017)), some as User-Interface layer (Ren et al., 2013; Zhang et al. ,2014) and some as

Table 7. 1 Architectures proposed for cloud-based manufacturing model

No.	Author	No. of layers	Layer
1.	"Introduction to cloud manufacturing" (Bohu, Lin and Xudong, 2010)	5	User layer Application layer Service layer Virtualised resource layer Physical layer
2.	"The architecture of cloud manufacturing and its key technologies research" (Ning et al., 2011)	6	Application layer Service-oriented layer Core Services Layer Virtual Resource layer Resource-oriented interface layer Physical layer
3.	"Cloud manufacturing: Needs, concept and architecture" (Wang, Zhou and Jing, 2012)	7	Ontology layer Manufacturing cloud layer Model layer for cloud manufacturing process Business cloud and resource cloud layer Business unit layer Manufacturing resources layer Infrastructure layer
4.	"Cloud manufacturing: a computing and service-oriented manufacturing model" (Tao et al., 2011)	7	Enterprise cooperation application layer Portal layer Application layer Core cloud service layer Virtual resource layer Perception layer Resource layer
5.	"Cloud manufacturing: A new manufacturing paradigm" (Zhang et al., 2012)	5	Application layer Middleware layer Service layer Perception layer Resource layer
6.	"From cloud computing to cloud manufacturing" (Xu, 2012)	4	Application layer Global Service layer Virtual Service layer Manufacturing Resource layer
7.	A Multi-view Model Study for the Architecture of Cloud Manufacturing (Lv, 2012)	5	Cloud manufacturing application layer Cloud manufacturing application interface layer Cloud manufacturing core service layer

			Cloud manufacturing virtual resource layer Cloud manufacturing physical resource layer
8.	“Cloud manufacturing: from concept to practice” (Ren et al., 2013)	5	User Interface layer Toolkit layer Middleware layer Virtual pool layer Resource perception layer
9.	“An architecture model of cloud manufacturing based on Multi-agent technology” (Zhang, Guo and Geng, 2014)	6	User Interface layer Service Management layer High Performance Computing layer Virtual Resource Standardization layer Resources Virtualization layer Resource layer
10.	“Cloud Manufacturing Analysis Based on Ontology Mapping and Multi Agent Systems” (Saeidlou, Saadat and Jules, 2014)	5	Service Application layer Portal layer Core functional layer Agent layer Resource layer
11.	“Cloud manufacturing – a critical review of recent development and future trends” Adamson et al. (2017)	6	Interface layer Application layer Cloud service layer Virtualization layer Perception layer Resource layer
12.	“Cloud manufacturing platform and architecture design” (Siderska and Mubarok, 2018)	6	Service-oriented layer Application layer Services layer Virtual resources layer Soft resources layer Physical resources layer

Application layer (Ning et al.,2011; Zhang et al, 2012, Xu, 2012), Service application layer (Saeidlou et al., 2014), Enterprise corporation application layer (Tao et al, 2011). This first layer is for all the users in the cloud terminal to make queries or request for services, via web portals or special manufacturing applications, with any terminal including mobile, PC, or special terminals. Some authors let the users access complex modelling tools, simulation terminals to construct a manufacturing application with the virtualized resources.

Customer billing is also included in this layer by some authors according to the service that is requested. Few authors have separated the application layer and the user interface layer as two different layers where the interfaces are separated from the specialized manufacturing applications.

Service-oriented layer/ Service-layer/Core-service layer/ Core-cloud service layer/ core-functional layer:

Ning et al. (2011) highlights this core-service layer as the most critical layer which acts as an intermediary between the upstream requesters and the downstream service providers. This layer may include the core services that is performed by the cloud service provider after the request is made. They include cloud service searching, matching, combining services, using high-performance computing. Wang et al. (2012) includes the search and match services in Model layer for manufacturing process.

This core cloud service layer includes optimal allocation, QoS management, fault tolerance, evaluation, scheduling and some include pricing calculation in this core service layer. Zhang et al. (2012), separates the services management in to two layers namely middleware layer (Ren et al., 2013) and services layer. Ren et al. (2013) includes the virtual resource instantiation, configuration, service matching in the virtual system management layer and includes tasks like service, composing, binding and executing in the cloud service management and combines these both as middleware layer.

Virtual resource layer/ cloud manufacturing virtual resource layer / virtual pool layer/ virtualization layer:

This virtualization layer includes the task of virtualizing the manufacturing resources and capacities (Zhang et al., 2014), containing a mass virtual database/ virtual pool for the resources to be analysed, grouped and packed (Ning et al.,2011). Saeidlou et al. (2014) includes the virtualization layer into the agent layer where task of resource discovery and management, is done by the agent in a multi-agent system.

Adamson et al. (2017), Siderska and Mubarok (2018), Tao et al. (20111) and every other author has combined virtualization and encapsulation in to the same layer, to provide the cloud service as a package. Zhang et al. (2012) names this virtual and encapsulation layer as service layer.

Perception layer:

Tao et al (2011), Zhang et al (2011), and Adamson et al (2017) have included a layer in between the physical resource layer and the virtualization layer called perception layer. The intelligent sensing and connecting to the network of physical resources layer. It includes technologies like IoT (Internet of Things), RFID to realise the overall connection to the manufacturing resources.

Physical layer/ Infrastructure layer/Resource layer/Physical resource layer:

This layer includes all the manufacturing resources and capabilities. Xu (2012) mentions that the physical resources can be present either in the hardware or software form, which may include equipment, employees, computers, servers, raw materials to simulation software, analysis tools and data standards.

7.6 Discussion

All the above-mentioned architectures of cloud manufacturing are based on three main actors namely, consumer, cloud service provider and the manufacturing resources. Layers concentrate on how the services are requested by the consumer and how the request is processed and routed to the network of manufacturing resources so that the resources are served to the consumer efficiently.

The concept of sub-contracting when the demand is high and unable to cope, by a manufacturing firm is nothing new to the manufacturing industry. But there are lots of hassles in sub-contracting like finding reliable suppliers, fail over plans

(Nwokocha, et al, 2019).

Elasticity is the key characteristic of cloud operating model. If the elastic capability is not realised by the consumer in real time, then the option of adopting cloud computing operational model in manufacturing environment is not going to reap the full benefits of migrating to the same. It is necessary to understand the elastic capability of cloud computing so as to acquire the full benefit of migrating to the cloud-based manufacturing system. Chapter 8 discusses the nature of elasticity, assessment of elasticity which would help the decision makers to assess if it is possible to realise the elastic capability in real time manufacturing environment. There has been a research study carried out by Yadekar et al., (2015) to assess the uncertainties of cloud manufacturing, but there has not been any research related to elasticity in manufacturing or emphasizing its importance, so far. This created a knowledge gap and has led to this novel research contribution. In the next chapter the researcher explores the concept of elasticity on the context of cloud-based manufacturing based on the concept of elasticity defined in cloud computing. The researcher also develops a framework and tool to assess the elastic capability, which is to be embedded in the cloud-based manufacturing system.

Chapter 8
Cloud Elasticity

8.1 Summary

This chapter discusses the challenges and issues that would arise on realising the elastic capability of the cloud based elastic manufacturing system in the real time manufacturing environment.

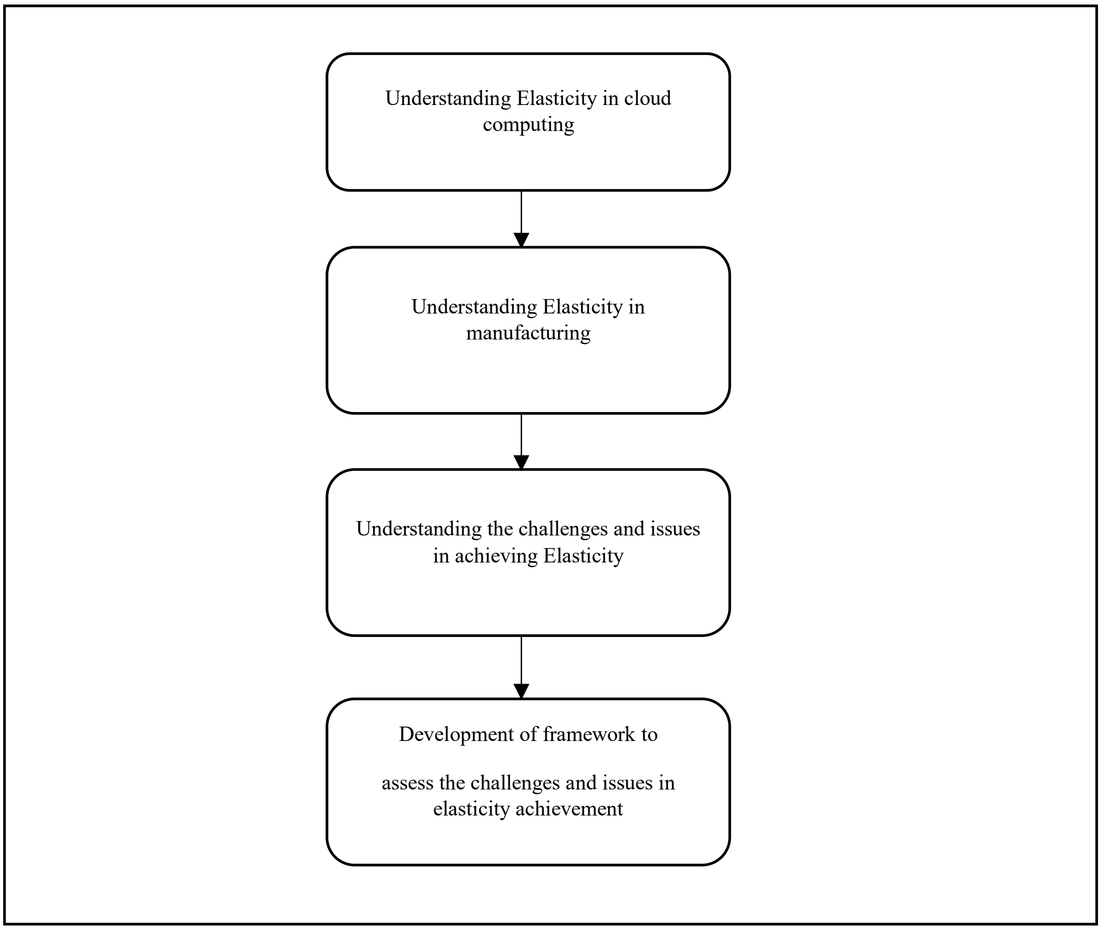

Fig 8. 1 Steps to develop framework for elasticity assessment

Firstly, the concept of elasticity on the context of cloud computing is explained along with the key terms associated with cloud elasticity. Secondly, the concept of elasticity on the context of cloud based elastic manufacturing system is explained. Thirdly, the challenges and issues that would arise in achieving this elastic capability in cloud-based manufacturing is explored. Finally, a tool is developed to assess the challenges in achieving elasticity and integrated in the cloud-based manufacturing model. The tool development involved the following steps as mentioned in the figure 8.1.

8.2 Step 1: Understanding elasticity in cloud computing

Rapid elasticity is the one of the essential characteristics of cloud computing, which would make the cloud adoption beneficial for the manufacturing firms. It is this elastic capability that would enable the realization of on-time delivery for the firms who adopt cloud. Only if elasticity is achieved in a cloud-based manufacturing system, the full potential and the benefits of adopting cloud operating model will be realised in real-time manufacturing environment.

Although the concept of cloud-based manufacturing emerged in 2010, there is no research that concentrates on the elastic capability of cloud-based manufacturing model (Siderska and Mubarok, 2018; Hatema et al.,2018).

There is an important issue that must be clarified before we proceed with the concept of elasticity and cloud based elastic manufacturing. So far, cloud adoption in manufacturing or any other industry means, receiving cloud IT services from IT cloud service providers, whereas cloud-based manufacturing system means using cloud operating model to receive manufacturing services. Cloud based manufacturing is service-oriented, collaborative, networked manufacturing, which has the same principle as that of cloud computing, whereas the computing hardware devices in cloud computing are replaced by physical manufacturing machines in cloud manufacturing.

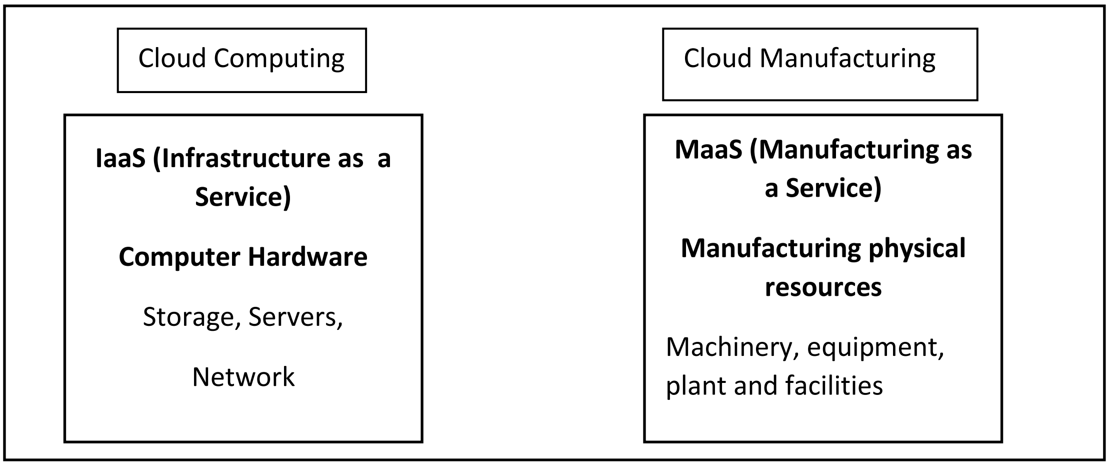

Fig 8. 2 Comparison of cloud computing and cloud manufacturing

8.2. 1 What is elasticity?

Although the term "Elasticity" is used primarily in the context of cloud computing, it lacks exact definition, methodology and metrics to measure and compare the systems with. Hence, it is not possible to quantify and compare elastic behaviour of cloud systems. (Herbst et al, 2013). On the context of Physics, the elasticity can be explained as follows:

> *"Elasticity, ability of a deformed material body to return to its original shape and size when the forces causing the deformation are removed. A body with this ability is said to behave (or respond) elastically." – (*Encyclopedia Britannica, 2019)
>
> *"Elasticity is the capability of an object to get back to its original state after being stretched/ deformation" – (*Herbst et al, 2013)

On the context of Economics, the elasticity can be defined as follows:

> *" it is a measure which represents how much the quantity demanded will be affected by a change in the price or income or change in the price of related goods."*
>
> \- (Ssag.sk, 2019)

On the context of cloud computing there are few definitions for elasticity which is highlighted in Table 8.1.

Table 8. 1 Cloud elasticity definitions

Source	Definition of elasticity (Rapid elasticity)
Badger et al., (2012)	*"Capabilities can be rapidly and elastically provisioned, in some cases automatically, to quickly scale out and rapidly released to quickly scale in. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be purchased in any quantity at any time."*
Herbst et al (2013)	*"In the context of cloud computing, Elasticity is defined as the ability of a system to automatically provision and deprovision computing resources on demand as workloads change."*
Mell and Grancs (2011)	*"Capabilities can be elastically provisioned and released, in some cases automatically, to scale rapidly outward and inward commensurate with demand. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be appropriated in any quantity at any time."*

8.3 Step 2: Understanding Elasticity in manufacturing

Based on the definitions for elasticity discussed above, elasticity in manufacturing may be defined as "*The ability of a manufacturing firm to scale out to expand its capabilities(resources) when the demand is high and scale in when the demand is low. It can be measured as the degree to which the firm is able to adapt to workload/demand* *changes". Elasticity enables the realisation of the competitive priority "on-time delivery".*

8.3. 1 Dimensions of Elasticity

Before exploring the dimensions of elasticity, it is useful to know important states of manufacturing system on the context of elasticity:

Under provisioned state: This is the state where the system can handle the demand or workload without stretching its capacity (scaling out) to match the demand or workload.

Over provisioned state: This is the state where the system is stretched or expanded (scaled out) to manage demand or workload in such a way that the capacity of its capability, matches with the demand or workload.

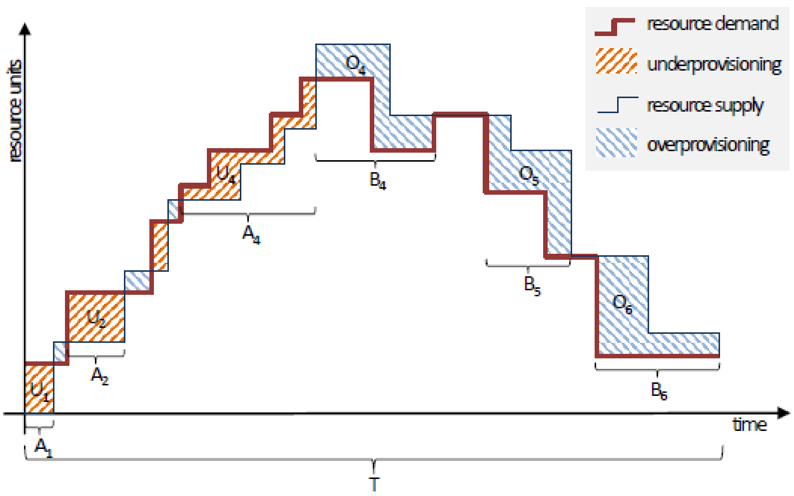

Fig 8. 3 Core elasticity metrics

(Souce: Herbst, Kounev and Reussner, 2013)

The Fig 8.3 shows the core elasticity metrics with time in the x-axis and resource units in the y-axis. This figure clearly illustrates the over provisioned state and under provisioned state, where,

$\bar{A}$ – average time to switch from under provisioned state to over provisioned state

$\sum A$ – accumulated time in under provisioned state

$\bar{U}$ - the average amount of underprovisioned resources during an underprovisioned period.

$\sum U$ - the accumulated amount of under provisioned resources.

$\sum B$, $\sum O$, $\bar{B}$, $\bar{O}$ are defined similarly for overprovisioned states.

There are two dimensions of elasticity that Herbst et al. (2013), highlights on the context of provision of computing resources. The same dimensions would suit manufacturing resources too. The two dimensions of elasticity in manufacturing are

1. Speed and
2. Precision

Speed: There are two ways of assessing the speed in elasticity. They are

1. Speed of scaling out
2. Speed of scaling in

Speed of scaling out: The speed of scaling out is the measurement of time, it takes to increase the capacity of the capabilities (manufacturing resources), i.e., switching from under provisioned state to over provisioned state.

Speed of scaling in: The speed of scaling in is the measurement of time, it takes to bounce back to its original capacity of the capabilities (manufacturing resources, i.e., switching from over provisioned state to under provisioned state.

Precision: The precision of scaling is the measurement of provision of resources in the over-provisioned state in such a way that the capacity of the manufacturing system in the over-provisioned state is able to exactly match the demand.

Speed and precision are very important metrics in elasticity quantification as they help to assess if the manufacturing system is able to scale out, in such a way that the manufacturer is able to deliver the product on-time despite having limited capacity of resources to finish the manufacturing tasks.

8.3. 2 Optimal elasticity:

Optimal elasticity is mostly limited to the resource scaling units. When assessing the elasticity, there should be a criterion based on which the amount of provisioned resources is matched with the actual demand so that the system's performance requirement is satisfied (Herbst et al., 2013). If a system is perfectly elastic, then the resources must match exactly with the demand with no delay in time, i.e., the resourcing should be instantaneous (Brebner, 2012).

8.4 Step 3: Understanding Challenges that would arise in realising elasticity:

This phase of the framework development involves identifying of the issues and challenges in achieving elasticity. This phase addresses the challenges and issues that would arise when proceeding towards the achievement of elasticity in manufacturing environment. The challenges that would arise to achieve the elastic capability of cloud based elastic manufacturing system have two dimensions.

- On the perspective of the consumer (service requester)
- On the perspective of the manufacturing cloud service provider

List of challenges: There are several challenges that would arise to realise the elastic capability of cloud based elastic manufacturing system.

8.4. 1 Challenges on the perspective of the consumer's manufacturing firm

Affordability – cost of the service, that which is requested by the consumer to the cloud based elastic manufacturing service provider

Response time – This is the time taken by the manufacturing resources to respond about its availability for the service requested and the availability of resources matching the requirement/ workload

Deployment of the resources to the task – cost and time taken to deploy the manufacturing services to the reliable manufacturing resources

Fail over – Contingency plans when the manufacturing resource meets with unexpected failure of the system, which in turn would affect the delivery time.

Trade-off - This is trade-off between cost and quality, time and quality, which the consumer must choose when requesting for a service.

Logistics issue – Cost, time and unexpected incidents that would affect the logistics.

Compliance issue- Issues that are involved with the regulatory compliances if the manufacturing resources are available in geographically remote places.

Reliability issue – Reliability factor based on cost, quality and on-time delivery

8.4. 2 Challenges on the perspective of cloud service provider:

Fail over- This is the contingency plan which the service provider must have in case of unexpected incidents when the service request is being processed.

Deployment of tasks to the available resources – Allocation of the task to the manufacturing resources, based on location, cost and availability.

Unpredictable workload requests – Plans to manage unpredictable workloads from multiple requests.

Cost - This is the cost of maintaining the resources available for occasional extreme load events**.**

Delay in response from the resources – Response waiting time involved as the consumer waits for the response from the cloud service provider, which in turn awaits the response from the manufacturing resource to respond about the availability.

Multiple request handling: Managing and matching the requests with the available resources

Finding and reserving a manufacturing resource: Matching and routing the request to the manufacturing resource and the time taken for the resource to respond

Elasticity level varies on the type of manufacturing request that is made (machinery, or software or skilled personnel).

All these factors mentioned above as the challenges in achieving elasticity is grouped based on the following dimensions:

COST	This involves the price charged for the service requested
QUALITY	Quality of the product or the service that is requested from the cloud service provider
TIME	Time taken to respond, lead, and deliver
COMPLIANCE	The regulatory issues involved, if the manufacturing resources involved are in geographically distributed

8.5 Step 4: Development of framework to assess the challenges and issues in elasticity achievement

This step involves assessment of challenges in achieving elasticity using Simple Multi-Attribute Rating Technique (SMART). MCDM (Multiple Criteria Decision Making) is a prominent modelling tool that helps in a decision-making process when there is a comparison of different points of view towards a certain decision (Kasie, 2013). SMART is a MCDM technique which is widely used in solving problems and decisions, which involves multiple criteria. This method helps the decision makers to decide when they face problems in choosing among multiple criteria.

This SMART technique helps to assess the challenges in achieving elasticity on four dimensions (cost, quality, time and compliance). This phase assesses the elasticity challenges which were identified in the previous phase. The findings from this assessment tool would help the manufacturing cloud service providers to decide on strategies to tackle the challenges that would hinder in realising the elastic capability of Cloud based elastic manufacturing system.

This chapter explains the methodology for prioritizing the challenges in achieving elasticity assessment in cloud manufacturing, so that the decision makers would find ways to manage these challenges when implementing cloud based elastic manufacturing system.

In this stage, all the challenges and issues which were highlighted, have been used to prioritize using SMART technique to bring out a ranking system for the challenges and issues in elasticity achievement.

8.5. 1 SMART (Simple Multi-Attribute Rating Technique):

A Decision Support System is a system that helps the decision maker to solve semi-structured problems by giving information or suggestions on a specific decision. Decision-making needs valid information to find alternative solution for the problem so that the final conclusion helps to yield maximum benefits (Siregar et al., 2017). SMART is a Multiple Criteria Decision-Making method where a best alternative is selected based on the weights of each of the criteria reflecting it relative importance (Kasie, 2013).

The advantage of using SMART technique is the simplicity of its questions as it is clearly understood by the decision maker about the process that is being used to find a solution. The process of rating the alternatives is mostly done based on the natural scales. SMART technique has been widely used in fields such as engineering, agriculture, military, security, manufacturing and assembly problems for the purpose of decision making in the planning activities. These decisions have been used to decide the site suitability, resources management, environmental impact assessment etc., (Rameshkumar Patel et al, 2017).

The SMART technique has been used in cloud manufacturing by Yadekar et al. (2015) for assessing the uncertainties. SMART technique is based on a linear additive model. This means that an overall value of a given alternative is calculated as the total sum of the performance score (value) of each criterion (attribute) multiplied with the weight of that criterion (Miroslawdabrowski.com, 2014). The main stages of the SMART technique involve the eight steps Oslon (1996), which are listed in the Table 8.2.

Table 8. 2 Stages in SMART technique

1. Identification of the decision makers. 2. Identification of the issues and purpose of decision 3. Identification of the alternatives to identify the outcomes of possible actions 4. Identification of the criteria with the dimensions limited to values 5. Assigning value for each criterion 6. Determining the weight of each criteria (most important criteria would be assigned 100) 7. Calculating a weighted average of the values assigned to each alternative, which allows normalization of the relative importance into weights which sums up to 1. 8. Making a provisional decision.

Source: Oslon (1996)

8.5. 2 Evaluation of challenges/ issues - Ranking:

- Identifying alternatives:

This step is done by writing a list of challenges and issues that would arise on the context of elasticity realisation in a cloud based elastic manufacturing environment. As a result of the previous stage a list of 19 challenges/issues which were categorized under two criteria, on the perspective of the consumer and on the perspective of the cloud manufacturing service provider.

- Identifying the selection criterion:

This step involves identifying the important dimensions in cloud based elastic manufacturing. The dimensions that were identified are cost, quality, delivery, compliance.

- Assigning relative weights:

This step involves assigning relative weights for each criterion that which were identified in the previous step. At the end of this step, a rating system evolves with each of the criterion involved. Each criterion will be ranked based on their level of criticality. Then scores are given to each criterion based on the ranking system.

- Assigning value for each challenge based on the weight:

This step involves assigning a score for each challenge based on their weight under each dimension. This gives some information about the impact factor of each challenge/issue under these four dimensions.

- Ranking the challenges/issues according to their weights:

This step involves multiplying each scaled value of the challenge factor into their weighted criterion, and all the scores are summed up for each challenge/ issue relating to achieving elasticity.

8.5. 3 Description of the dimensions:

Cost: This involves the delivery cost of the product or receiving any manufacturing resource service from the service provider on a specific time.

Quality: The involves the quality of the product or the service that will be delivered by the cloud service provider. Though there will be SLA for quality assurance, any upcoming manufacturing firm willing to receive the service for the first time, would hesitate to rely on the quality match.

Time: This challenge very critical which makes this elasticity a unique factor. Time comprises of response time, resource accumulation time, lead time, delivery time.

Compliance: This involves the industry and government regulation, especially when the resources are geographically remote from the service consumer.

8.5. 4 Process of prioritizing:

SMART is the best MCDM technique for the proposed model, since it helps the decision maker to understand the issues that would arise on the context of different criteria. The following are the steps involved as shown in Fig 8.4.

Step 1: The decision maker is the user or the expert, who wants to assess the challenges/issues

Step 2: The user chooses the challenges to be analysed

Step 3: The uses ranks the challenges based on the dimensions (Cost, Quality, Time, Compliance)

Step 4: For instance, if the user gives the following ranks and weights, it finally provides them a ranking system to assess which challenge/ issue needs to be given more importance to achieve elasticity. This is shown in Fig 8.4.

Ranking to assess the important challenge/issue in achieveing elasticity
Rank - holds values between 1-10 (1 being the least and 10 being the most)
Weight - holds the value between 10- 100 (10 being less important)

Dimensions	Rank (1-10)	Weight (10-100)	Normalised weight
Cost	3	70	0.26
Quality	2	80	0.3
Time	1	90	0.33
Compliance	4	30	0.11

Fig 8. 4 Elasticity challenges dimensions weighing

Step 5: Involves assigning values for each challenge/issue. This is based on each dimension of cost, quality, time and compliance, with values ranging on a scale from 0 - 10.

Step 6: The value of each challenge is calculated by the product of each scaled value of the challenge and their corresponding weight dimension and then summing up all the scores for each challenge (Fig 8.5).

Please value the challenges on a scale of 0 -10 to find the average weight of each challenge					
Challenge/issue in achieving elasticity	Cost	Quality	Complaince	Time	Total weight
	0.26	0.3	0.11	0.33	
Cost of service	10	7	6	3	6.35
Response time	8	7	10	4	6.6
Availability of resources	8	5	9	8	7.21
Deployement of resources	7	5	10	8	7.06
Fail over	10	6	9	5	7.04
Trade off	10	10	9	3	7.58
Logistics	7	3	9	10	7.01
Compliance	6	6	10	10	7.76
Reliability	6	10	9	10	8.85
Unpredictable workload requests	8	3	7	10	7.05
Cost of maintenance	10	3	2	4	5.04
Delay in response for request	9	2	10	9	7.01
Finding resources and matching	6	2	8	10	6.34
multiple similar request handling	10	7	9	10	8.99
Availability of variety of mfg resources	3	4	10	10	6.38

Fig 8. 5 Elasticity challenges/issues in total weight

8.5. 5 Elasticity Assessment tool

There are three sections in the tool:

- User information section – helps to identify the type of the tool user, if it is a consumer or the manufacturing cloud service provider.
- Dimensions ranking section – ranks the dimensions based on the user input values.
- Prioritization section: This section helps the decision maker to prioritize the challenges / issues highlighted by the user.

The three sections in the tool provides various options for the user to choose the challenges/issues to compare and prioritize. The user ranks the dimensions of the challenges before assessing the weight of each challenge/issue that would arise when realising the elastic capability of a cloud based elastic manufacturing system.

8.5. 6 Tool prototype

Figures 8.6,8.7 and 8.8 are snapshots of the interface of the tool, that which helps the decision makers to prioritize the elasticity challenges and issues that would arise, when implementing cloud based elastic manufacturing system.

User Information section:

Fig 8.6 illustrates the first section of the tool, where the users select one of the options between the consumer and the cloud service provider. The priorities and concerns vary based on the different type of user.

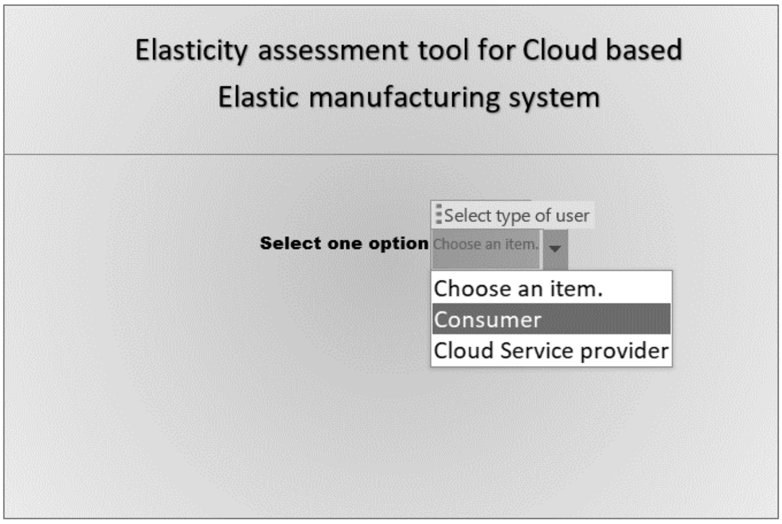

Fig 8. 6 User Information section

Fig 8.7 illustrates the second section of the tool where the user gives weights to the four dimensions according to their preference which may be influenced by the factors associated with the demand and the current situation in the firm.

Elasticity assessment tool for Cloud based
Elastic manufacturing system

Dimensions	Rank	Weight	Normalised Weight
	(1-10)	(10-100)	
COST	Choose an item.		
QUALITY	Choose an item.		
TIME	Choose an item.		
COMPLIANCE	Choose an item.		

Fig 8. 7 Dimensions Ranking section

Elasticity assessment tool for Cloud based
Elastic manufacturing system

User: Manufacturing Cloud Service Provider

Challenges or issues	Cost (1-10)	Quality (1-10)	Time (1-10)	Compliance (1-10)	Total weight
Cost of service (low-cost production)					
Response time (from resources)					
Availability of resources					
Fail over plan					
Unpredictable workload requests					
Logistics contingencies					
Compliance issues					
Deployment of resources					
Cost of maintenance					
Delay in response					
Finding resources and matching					
Multiple similar requests handling					

Fig 8. 8 Elasticity Challenges/issues prioritization section

Fig 8.8 shows the template where the user will be able to arrive at the final decision on the prioritization based on the total weight to the the challenge that has to be concentrated before proceeding with the cloud-based manufacturing model.

8.6 Limitation of the elasticity assessment framework:

The elastic factor that is considered in this model is focussed towards the context of cloud computing is IaaS (Infrastructure as a Service). It is reflected in the cloud-based manufacturing model where only physical manufacturing resources like machineries, logistics are taken into account. This may be considered as the limitation of the model. The concept of elasticity that is considered on the context of cloud based elastic manufacturing is physical MaaS (Manufacturing as a service) which involves physical manufacturing resources. This is the limitation of this framework and assessment of elasticity.

Chapter 9

Architecture of Cloud based Elastic Manufacturing Model (CEMM)

9.1 Architecture of Cloud based Elastic Manufacturing Model

A cloud architecture of a system refers to the components and sub components in a system, and the relationship between them, which may be designed to leverage the power of the resources in the cloud to solve various business issues (Hcltech.com, n.d.).

This architectural model (Fig 8.10), has seven layers:

- User-Interface layer
- Elasticity Assessment and Decision Support layer.
- Manufacturing Core Service Management layer.
- Service encapsulation layer
- Manufacturing resource virtualization layer
- Manufacturing networking layer
- Manufacturing physical resources layer

The first two layers focus on the consumer's request and assessment of elastic capability, feasibility of the request. This is followed by the middle man layer called Manufacturing Core Service Management layer, where all the processes such as manufacturing cloud resource search triggering, matching are involved. The four layers below to this middle man layer are the critical layers that enables the realization of the actual application of cloud operating model in manufacturing i.e., networking, routing, virtualizing and encapsulating the physical manufacturing resources.

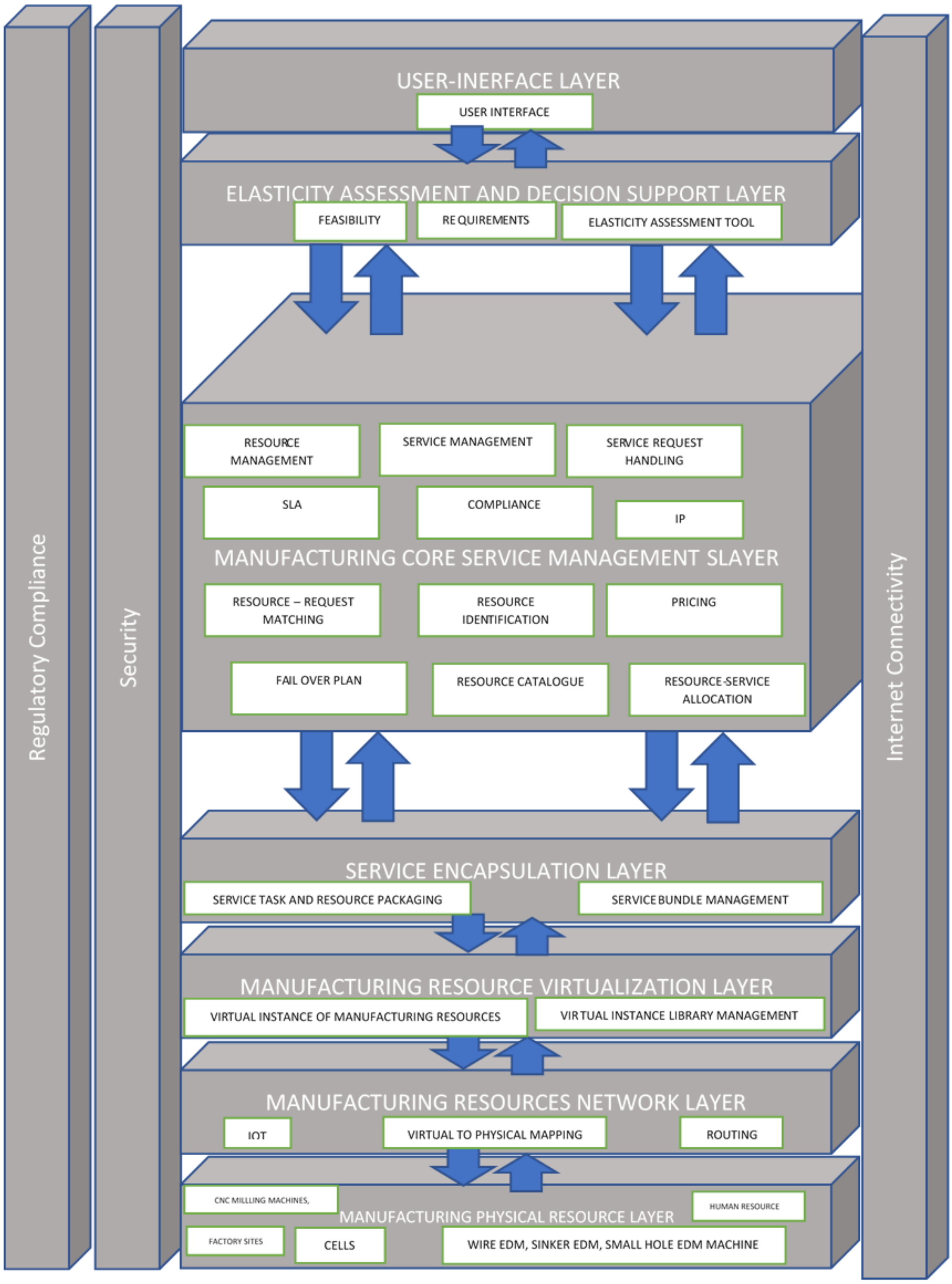

Fig 9. 1 Architecture of Cloud based Elastic Manufacturing Model

- **User-Interface layer:**

User-Interface layer is the layer through which the consumer communicates with the cloud manufacturing service provider. It is the initial point of a session where a communication begins with a service request with specifications, pricing to the service delivery. The interface can be a thin-client interface such as web browser, through any device from PC to mobile devices, with an internet connection. This user interface can have drag and drop visual controls for the data entry and help the consumer to visualize the real-time output of the service. The web interfaces should empower their consumers to administer, monitor the manufacturing resources as if they own them. This layer is more user-centric where the consumer exercise more control, with choices and flexibility.

- **Elasticity Assessment and Decision Support layer:**

This is the layer where the user assesses if it is possible to attain elasticity, based on the elasticity assessment tool. This layer also assesses the requirements for its feasibility to achieve the required elasticity. Procedures like investigating if the cloud service provider's service would meet the need and expectation of the consumer takes place in this layer. This layer has the components such as user requirement, technical requirement including support for planning, integrating and organizing them. Although requirement management is involved throughout the process until the service is delivered, it is here the consumers, and cloud service providers communicate and make adjustments with the requirements, if needed. Elasticity assessment tool plays an important role in this layer. It helps the user to assess the feasibility of the cloud-based service offering based on the requirements of the user. If the user is not happy with the result of the assessment, the user may decide if it is necessary or affordable to proceed with the cloud-based service offering.

- **Manufacturing Core Service Management Layer:**

This is the next layer which acts as an intermediary that connects requirements (above) and the capabilities (below). This layer is accessible only by the cloud service provider where all the services are managed, catalogues of capabilities are maintained, Service Level Agreements are laid out to highlight the responsibilities and expectations on both the parties involved and to sort out any issues relevant to any specific service requested by the consumer to avoid chaos when any issue occurs and for both the parties to have a clear understanding of the requirements. Service description, scope, mutual responsibilities, reliability, security, service performance, pricing method, service availability are all discussed in this layer. Manufacturing Service Level Agreement, Manufacturing service catalogue management, manufacturing capacity management, manufacturing service availability management, manufacturing service continuity management, information security management, supplier details management are all included in this layer and is managed by the cloud service provider.

- **Manufacturing Physical Resource Layer:**

Pool of physical manufacturing resources exist in this layer. All these manufacturing resources including machinery, human resources, raw materials, and other manufacturing capabilities are connected and communicate to the cloud service provider. Each manufacturing resource is registered with the cloud service provider with its own specifications, specialities, skills and capabilities. It resembles more like "Crowd sourcing", where all the manufacturing resources pour in their expertise into the cloud service provider's library/database. Each manufacturing resource would continue to do their own task and when a request arrives from the cloud service provider (based on the specification from the consumer), the request is accepted if the manufacturing resource is available and ready to handle the request, or if it is ready to share its manufacturing resources, else, it is expected to report its unavailability.

- **Service Encapsulation Layer:**

In this layer, the available manufacturing resources are bundled up, encapsulated as a package to be provided to the consumer. This is the unique capability of the cloud-based manufacturing. Here the virtual instances of manufacturing resources are bundled up and provided as a service to the consumer as per the demand.

- **Manufacturing Resource Virtualization Layer:**

This layer contains the virtual instance of the manufacturing resources. A virtual library of the physical manufacturing resources. This layer helps the cloud service provider to simulate the actual service offering, before it is encapsulated and provided as a package to the consumer.

- **Manufacturing Network Layer:**

This layer connects the cloud service provider and the physical resources by identifying them, perceiving them and then find a route to connect and communicate with them to know the availability of the manufacturing resources and then virtualise and encapsulate and provide it as a service.

9.2 Advantages in CEMM:

- **On-demand service:**

SMEs can request for service on-demand. The hassle of outsourcing, finding a reliable supplier, searching for a manufacturing company with a similar expertise and quality control are taken care of by the third party. The SME can just request for the service with the specifications needed for the service.

- **Rapid Elasticity:**

The firm requesting a manufacturing service will be able to scale its resources by getting it as a service instead of owning them and spending on the capital cost of the resources. The firm will be able to scale up and down as and when the demand for its product increases. This way, the firm will be able to realise the unique elastic capability of cloud-based manufacturing services.

- **Measured Service and pay-as-you go pricing:**

The manufacturing service is provisioned as a utility, which makes it affordable for the manufacturing SMEs. The SME requesting the service from the cloud service provider needs to pay just for the service it receives on a pay-as-you-go basis. SME has to pay for the data which they have used and not more. This facility would benefit the SMEs which has cost constraint. This new mode of manufacturing helps SMEs to convert CAPEX to OPEX.

- **Cloud broker/ cloud service provider:**

Most of the time the manufacturing cloud service provider acts like a broker in between the consumer and the available pool of manufacturing resources. The cloud service provider provides a platform for the manufacturing SMEs to request, receive the manufacturing capabilities.

- **Cost of Capital:**

SMEs who struggle to start up their business due to high upfront cost will benefit more on this mode of manufacturing. The SMEs can rent the machinery or any other manufacturing resource as a service from a third-party cloud service provider who is responsible for the quality, security, reliability of the product and the service. The SME can concentrate on its core production, instead of worrying about the cost of investing in manufacturing resources.

- **Outsourcing:**

Outsourcing manufacturing task may not be new in the manufacturing industry, but the outsourcing task taken as a responsibility by a third party and provided as a service, with the assurance of quality, reliability and security is new. Cloud-based manufacturing model involves a networked centralised management of outsourcing by a third-party service provider.

- **Efficient resource utilization:**

This cloud based elastic manufacturing is a type of collaborative manufacturing, which involves all the SMEs registered with the cloud service provider. If a SME wants to be a part of manufacturing resources pool, it has to sign up with the cloud service provider with its capabilities, skills and expertise. This SME will be allocated a task according to the service demand in this networked, collaborative manufacturing framework. The SME will always be allocated a task when its capabilities are available. This might reduce resource idleness leading to an efficient way of utilizing manufacturing resources.

9.3 Challenges in implementing CEMM:

- **Knowledge about Cloud:**

Knowledge about cloud-based elastic manufacturing will be new for core manufacturing SMEs. This may lead to many manufacturing SMEs being hesitant to move to this mode of manufacturing until they get a clear and understanding of how this networked manufacturing cloud mode works in real time. Probably it will take few years to realise the advantages of this mode of manufacturing in real time.

- **Intellectual property and security glitches:**

Firms who request for services would hesitate to reveal their business-related intellectual property in a public platform, which is shared by many other firms. Since there is a potential for infringement in the publicly shared platform, firms should be convinced about the protection of their Intellectual property before they decide to adopt CEMM. Since the intellectual property is based on territorial rights, it's difficult and a tedious job for the cloud service provider to comply with the rules in a dynamic ever-demanding manufacturing environment.

- **Readiness to share resources:**

As the firms are expected to disclose their expertise to the cloud service provider and share their surplus resources with an unknown consumer for a service, this would cause majority of the firms to hesitate to volunteer to share their resources.

- **Reliability and lack of control of data:**

Firms may not be sure about the reliability of the cloud service provider as they provide their specifications and data to a third party. In this cloud environment, the consumer may not know the whereabouts of its data stored in the knowledge base. Information will be stored in a location which may be beyond the control of the consumer. These issues would bother SMEs to completely rely on third party cloud service provider as it might pose a threat against the consumer’s trade secrets, in spite of Service Level Agreements and terms and conditions signed by both the parties.

9.4 Conclusion and limitations:

Cloud based Elastic manufacturing system is networked, collaborative manufacturing mode based on the operating model of cloud computing in the Smart Manufacturing environment. This model is novel in the following ways:

- By the introduction of Elasticity Assessment tool and Decision Support layer

Currently, this model is in the conceptual level and has not been implemented in real-time manufacturing environment, but it paves way for further research in the field of Smart Manufacturing. This cloud based elastic manufacturing system has been designed on the basics of the cloud manufacturing models discussed in chapter 7. However, integration of elasticity assessment tool in to the framework is novel in this model. This chapter lays foundation to explore and assess the challenges that would arise in implementing the cloud-based elastic manufacturing system in real-time manufacturing environment, for further research.

PART V-VALIDATION

Chapter 10
Validation of the model

10.1 Introduction

Cloud based elastic manufacturing model has been proposed to improve manufacturing performance by enabling firms to achieve on-time delivery hence improving the manufacturing performance. A simulation of a real-time manufacturing environment has been replicated using WITNESS simulation software to arrive at the important parameters that has to be considered to improve the manufacturing performance. Then the parameters were compared in R-studio, to find the best combination, which has high correlation amongst them to promote on-time delivery thus improving the manufacturing performance.

This hypothetical case study attempts to validate the CEMM capability to overcome the loss of opportunity that happens when a SME is not able to cope with the increasing demand for its components. Limited resource availability and on-time delivery being the main constraints, a SME would struggle to meet the sudden fluctuating demand and thereby fail to sustain its competitive advantage. Service-oriented cloud-based elastic manufacturing business model could support SME in such delicate situation.

Case 1:

The need for sequenced on-time delivery of the components to meet the market demand has been an ongoing issue, which is yet to be addressed by efficient business models in the manufacturing industry. When a sudden increase in demand arises, SMEs struggle to find solution to manage and are forced to invest in the fixed resources such as infrastructure and machinery to cope with uncertainty in demand and workload. SMEs suffer financial loss due to capital investment when equipment are idle when production is low due to low demand. This situation makes SMEs to be more cautious and reluctant to invest in excessive production facilities. However, this situation backfires whenever there in an increase in demand whereby the firms are not able to meet the increased demand due to insufficient resources. Even if they decide to outsource the production, they must find suppliers or other production companies on their own. This leads the firms to lose focus on core business activities. In addition, it is more tedious to find reliable suppliers or the reliable production units since sub-contracting has been a painstaking process. The possible negative outcome of outsourcing are low-quality products and delayed delivery. The inability to cope with the change in demand is because of the firm being less elastic in their manufacturing processes. Service-oriented cloud-based elastic manufacturing business model would minimise the problem and aid SMEs to cope with such scenarios.

Problem description:

A hypothetical component manufacturing firm from online open source was considered for this case study (www.data.gov, https://data.world/datasets/manufacturing). Although the manufacturing firm considered for the validation study is hypothetical, the data set used closely reflects the real-time manufacturing parameters and outputs. The chosen SME manufactures automobile components. The company suffers by not being able to meet the fluctuating demand and on time delivery. The company is able to meet only 90% of the orders and faced the loss of opportunity due to the inability to cope with the excess production of 10% The reasons for the loss of opportunity is that the company is not able to cope with unexpected increase in demand for a particular precision component. The company is hesitant to reinvest in additional machinery to cope with temporary increase in demand. The firm's reluctance to invest in the new machinery is that it believes that the additional equipment will stay idle and under exploited during low demand.

The company in the case study manufactures two different types of components. There are two production lines, A and B to produce the different components simultaneously. When demand for component increases, problems in production such bottleneck equipment breakdown and longer waiting time arise and affect the production flow. This shows that the production processes and manufacturing system in the firm are not flexible enough to cope with the fluctuations in the market demand and unable to find an alternative approach to cope with the production problem.

Table 10.1 shows the details of production for the components A and B

Production line	No. of components	Demand/day (during peak time)
Model A/ line	400/shift=>800/day	600/shift=>1200/day
Model B/line	400/shift=>800/day	400/shift=> 800/day

Table 10.1 Production of components A and B

In the first case, the demand for the component model A is high. The production capacity for model A is 400 c per shift and 800/day. A. The requirement from production line A is 600/shift, which leads to 1200/day. Nevertheless, the firm is not able to cope with increase in demand for the component. This is clearly due to the limited availability and capacity of the resources. The company loses its profit by producing 400 unit /day less than need to meet the demand.

Production line manufacturing model B suffers frequent bottleneck problems, equipment failure and downtime. The company is unable to produce required model B components and deliver on time. This unpredicted downtime would force the company to outsource or sub-contract the production process to meet the demand. The company struggles to find a reliable and trustworthy company to outsource it manufacturing activities. A centralised service-oriented approach such as CEMM would help the firm to cope such situation in supporting the firm with low-cost manufacturing and on-time delivery.

WITNESS simulation software has been used to study one such scenario with variety of manufacturing problems to identify the most feasible, low-cost and reliable approach to achieve a smooth production flow. This simulation helps to identify the critical parameters that should be considered to achieve on-time delivery, thus improving the overall manufacturing performance.

WITNESS – Simulation software

WITNESS Manufacturing Simulation software (Lanner.com, n.d.) has been used for this study. WITNESS has been used in the validation study to model a real-time manufacturing environment and assess the capability of the production lines.

WITNESS simulation software enables to develop models and simulation applications to provide an incomparable level of insight through dynamic data visualisation. Witness is one of the main simulation systems used by many organisations for manufacturing simulations. WITNESS provides freedom to test various options in a virtual environment, which is risk free.

10.2 WITNESS simulation

Virtual company A manufactures spark plugs. The product is made of a centre electrode, metal casing or shell and side electrode (ground electrode). In other to manufacture copper and nickel spark plug, the production process goes through five stages as listed below

- Extruding is made on a metal bar to make a blank.
- For further shaping on the blank to its required dimension as well as to achieve the hard shape the lathing machine is used.
- The casting banding attachment of the side electrode
- Ceramic insulation
- Inserting of terminal stud and welding of the centre electrode

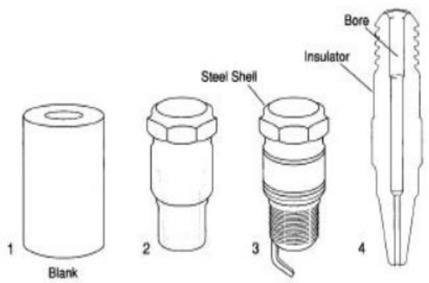

Fig 10. 1 Manufacturing processes 1-3

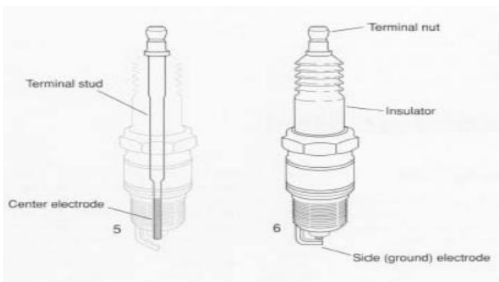

Fig 10. 2 Manufacturing processes 4 and 5

10.2. 1 Data collection

Hypothetical data of the manufacturing firms was used in the simulation study.

10.2. 2 Building the model

Using witness, a gearbox manufacturing plan was created for given conditions of the product to achieve a low-cost manufacturing approach and meeting the delivery time. Parts like ceramic and insulator come from external suppliers, which is then passed through the conveyer belt, then assembled and finally inspected before shipment. CNC machines are used in the production.

Witness simulation is an effective tool used in operations research and management science. The application of the particular process is used to simulate a model of manufacturing process, which is then analysed and then put into action. Different types of factors can be calculated using this system. Production factors such as costs and lead-time can be comprehended with the ability to adjust and arrange things into different positions according to what is required.

Simulation models also have the function to assess the value of any set of specifications. They are optimised to convert and observe the input parameters into possible output results. Optimization can be used to help control different number of operators and machines including the ability to maintain costs and use resources responsibly. The cycle time of the process can also be adjusted depending on the formulation of the constraints.

When manufacturing problems are being considered, the methodology of stochastic approximation is used due to its relationship with gradient search. However, if it's different from simulation, changes can occur and take place in the system during cautious event simulations, while it is nearly impossible to make any changes to the parameter during continuous event simulation. In addition, this approximation mentioned mainly focuses on a wide range of variable problems which can occur during the production runs.

Simulation experimentation

Fig 10.3 demonstrates the complete virtual assembly of copper/nickel flash fittings of spark plugs. Simulation was run for 60 mins and 500 mins and 40 hours respectively and machine statistics were observed.

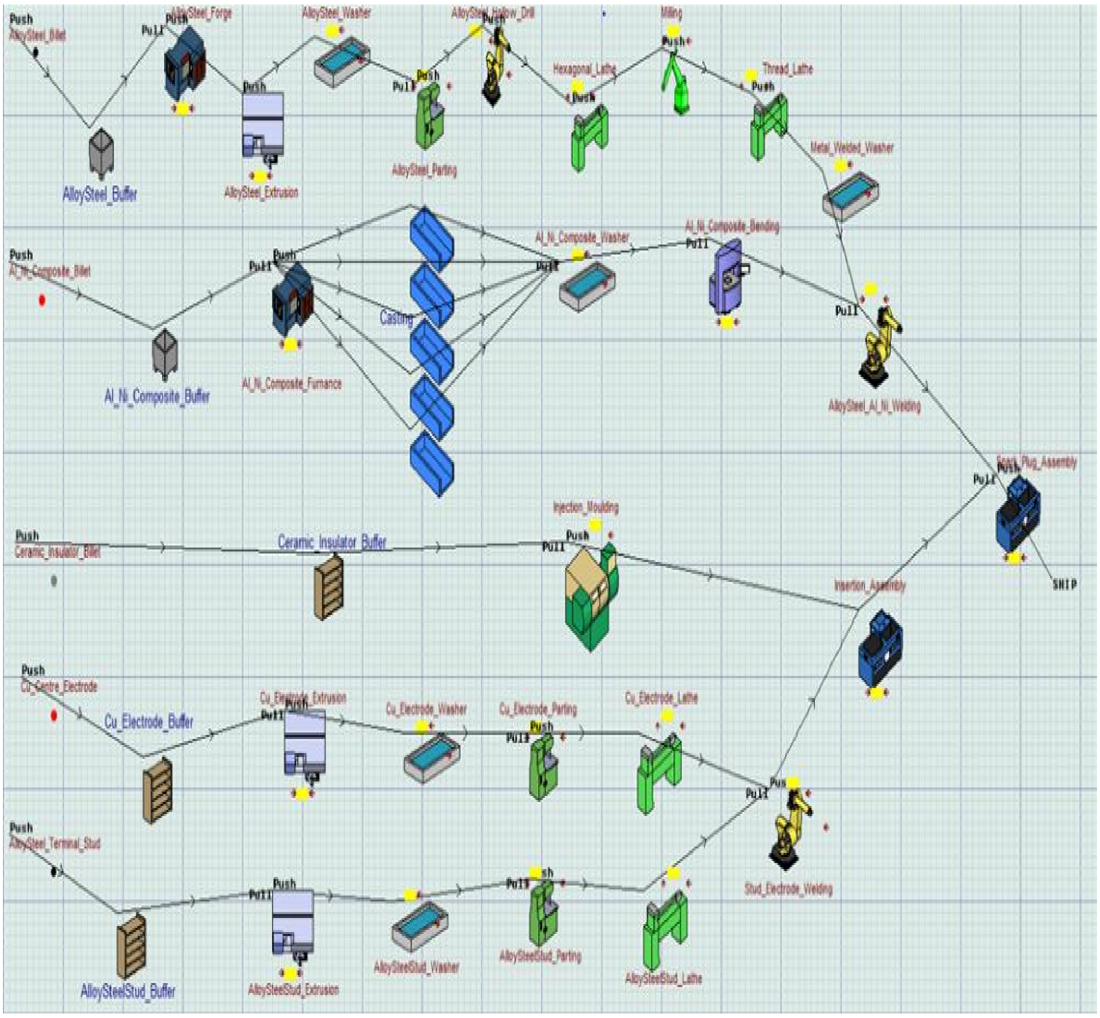

Fig 10. 3 Virtual assemble of spark plug

The following figures highlights the production runs at various time frames. Only few of the machine statistics have been presented here in this chapter and left the others in the Appendix A, B and C respectively.

10.2. 3 Machine statistics for 60 min production run:

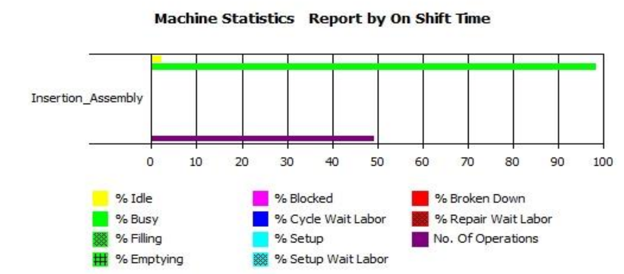

Fig 10. 4 Machine statistics for Insertion_Assembly (60 mins)

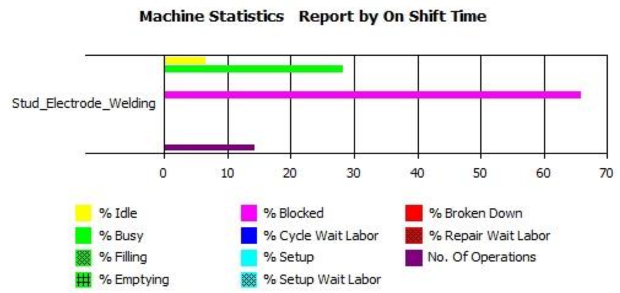

Fig 10. 5 Machine statistics for Stud_Electrode_Welding (60 mins)

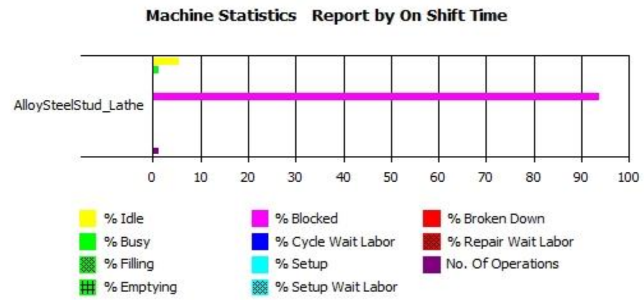

Fig 10. 6 Machine statistics for Alloy Steel Stud_Lathe (60 mins)

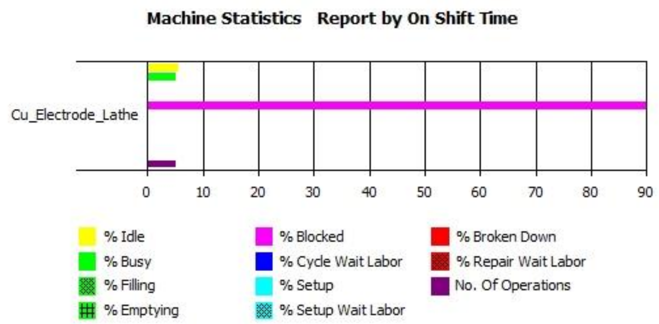

Fig 10. 7 Machine statistics for Cu_Electrode_Lathe (60 mins)

10.2. 4 Machine statistics for 500 min production run

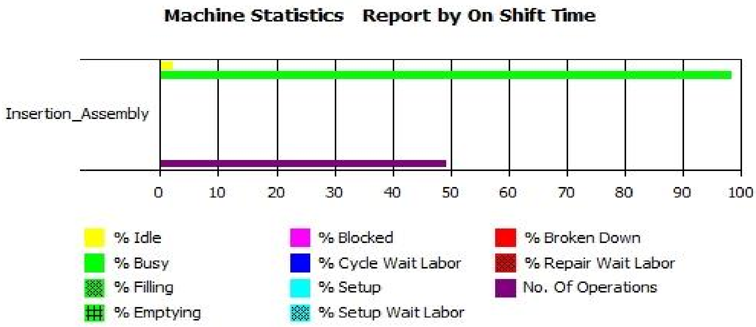

Fig 10. 8 Machine statistics for Insertion Assembly (500 min)

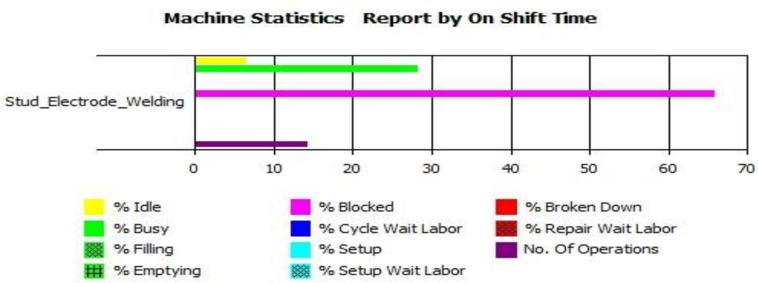

Fig 10. 9 Machine statistics for Stud_Electrode_Welding (500 min)

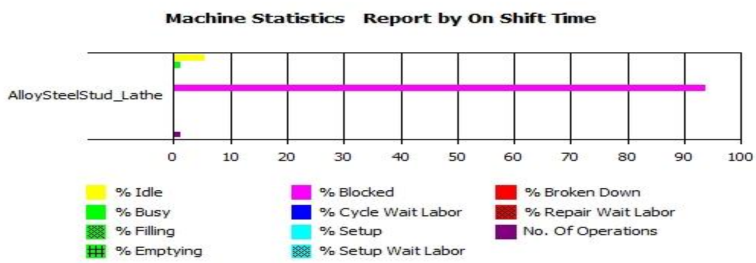

Fig 10. 10 Machine statistics for AlloySteelStud_Lathe (500 min)

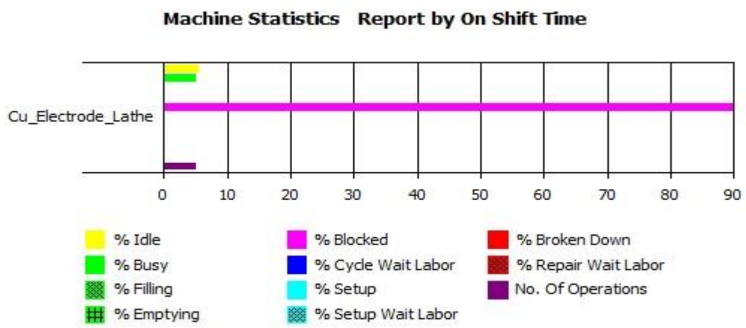

Fig 10. 11 Machine statistics for Cu_Electrode_Lathe (500 min)

10.2. 5 Discussion

This simulation study has replicated a real-time manufacturing environment, where the production is run at different sets of time. These production runs have helped to analyse the issues that would arise in a production unit and identify the possible causes for the delay in delivery of the product, hence affecting the overall manufacturing performance. This study has helped to identify the capability of a bottle-neck machine to delay the production. In the above production runs, such bottle neck machines have increased idle time of the preceding machines waiting for them to finish the task, thus making the production inefficient. The machine statistics in this simulation shows that there are machines which are in-capable to handle the task on-time and become a bottle-neck. Bottle neck machines have the limited capacity to do the allocated task. So, the firm has to find an alternative solution.

The solution may be to replace the machine, which could cost more. This suggests that scaling-out may be a better solution for such scenario, if it is comparatively cost effective and deliver the product on-time. To identify if it is cost-effective, the user can utilize the elastic assessment tool to raise concern about the cost of the manufacturing service to the cloud service provider and assess if moving to cloud service would be a better option to improve its manufacturing performance. In the simulation study there were various instances where the production has not been efficient. Analysing the parameters that would affect the manufacturing performance, a set of ten parameters were jotted down. These parameters are found to affect the manufacturing performance. The statistical analysis in the next section includes these parameters to find out the best combination which has high significance of correlation to achieve on-time delivery, hence improving the manufacturing performance.

10.3 R-Studio:

This section discusses the validation of CEMM using R-studio software. The goal of this statistical analysis is to identify the best combination of the variables which has high significance to optimize the manufacturing performance by achieving on-time delivery.

10.3. 1 Overview of RStudio

R is an open source software program for statistical analysis, based on the S language. It is widely used by statisticians, researchers, data analysts for statistical computing and data analytics. It has an easy-to-use interface, which is organized to help the user to clearly view graphs, data tables, R code, and the output at the same time.

The sample dataset that has been used for this analysis is available in the appendix D. Following steps were carried out the validation process

1. Downloading/importing data in R
2. Transforming Data / Running queries on data
3. Basic data analysis using statistical averages
4. Plotting data distribution
5. Analysis and interpretation

260 virtual manufacturing SMEs identified from open sources were configured, and 10 parameters identified in the simulation study were the variables considered for the analysis. Appendix C shows the summary of the data set (hypothetical). Variables selected for the validation study are listed below:

- No of workers
- Turnover (£)
- Production rate/day
- Machining flexibility (%)
- Operation agility (%)
- Machine idle time (%)
- Breakdown time (%)
- Machine set up time (min/hr)
- Annual inventory cost (£1000s)
- on time delivery (yes -1 or no-0)
- Reject rate (%)
- Resource utilization (%)
- Total production lead time (in days)

10.3. 2 Data analysis

- **Session 1 Data summary**

Following section shows the data summary and explains the structure of the data set.

```
> library(readxl)
> Cloud_FrameworkAS_newF2 <- read_excel("F:/Arun New Project/Cloud FrameworkAS newF2.xlsx")
> View(Cloud_FrameworkAS_newF2)
> attach(Cloud_FrameworkAS_newF2)
> head(Cloud_FrameworkAS_newF2)
# A tibble: 6 × 14

  `Name of company` `No of workers = >100` `Turnover (£ M)`
          <chr>              <chr>          <dbl>
1          BCS               Yes            12.5
2          AKN                No             2.0
3          KKC               Yes             5.0
4          CMN                Yes            4.0
5          RUS               Yes            1.0
6          PEN               No             2.0
# ... with 11 more variables: `Production rate/day` <dbl>,
#   `Machining flexibility (%)` <dbl>, `Operation agility(
#   %)` <dbl>, `Machine idle time (%)` <dbl>, `Breakdown time
#   (%)` <dbl>, `Machine set up time (min/hr)` <dbl>, `Annual
#   inventory cost (£1000s)` <dbl>, `ontime delivery (yes -1
#   or no-0)` <dbl>, `Reject rate (%)` <dbl>, `Resource
#   utilization (%)` <dbl>, `Total production lead time( in
#   days)` <dbl>
```

> summary(Cloud_FrameworkAS_newF2)

```
 Name of company    No of workers = >100 Turnover (£ M)
 Length:260         Length:260          Min.   :  0.200
 Class :character   Class :character    1st Qu.:  3.575
 Mode  :character   Mode  :character    Median :  9.000
                                        Mean   : 11.738
                                        3rd Qu.: 17.000
                                        Max.   :107.000
```

- **Session 2 Details of variables**

The following section shows the details of the individual variables:

```
 Production rate/day Machining flexibility (%)
 Min.   :   5.00    Min.   : 0.00
 1st Qu.:  29.75    1st Qu.:55.50
 Median :  71.50    Median :65.95
 Mean   : 139.89    Mean   :64.61
 3rd Qu.: 125.00    3rd Qu.:77.00
 Max.   :3000.00    Max.   :99.00

 Operation agility( %) Machine idle time (%)
 Min.   : 8.00      Min.   : 0.90
 1st Qu.:19.82      1st Qu.: 20.98
 Median :29.65      Median : 29.25
 Mean   :33.13      Mean   : 30.60
 3rd Qu.:40.33      3rd Qu.: 37.70
```

Max. :98.00 Max. :337.00

Breakdown time (%) Machine set up time (min/hr)

```
Min.   : 5.00     Min.   : 1.00
1st Qu.: 21.90    1st Qu.: 7.00
Median : 29.15    Median :10.50
Mean   : 31.61    Mean   :12.07
3rd Qu.: 37.70    3rd Qu.:15.95
Max.   :508.00    Max.   :30.00
                  NA's   :1
```

Annual inventory cost (£1000s)

```
Min.   : 50.0
1st Qu.: 99.0
Median :119.0
Mean   :123.9
3rd Qu.:145.8
Max.   :260.0
```

On-time delivery (yes -1 or no-0) Reject rate (%)

```
Min.   :0.0      Min.   :   2.80
1st Qu.:0.0      1st Qu.:  22.25
Median :1.0      Median :  30.15
Mean   :0.6      Mean   :  45.31
3rd Qu.:1.0      3rd Qu.:  38.12
Max.   :1.0      Max.   :2105.00
```

Resource utilization (%)

```
Min.   : 3.00
1st Qu.:44.65
Median :54.50
Mean   :52.02
3rd Qu.:60.50
Max.   :73.70
```

Total production lead time(in days)

```
Min.   : 5.00
1st Qu.:10.00
Median :10.00
Mean   :12.15
3rd Qu.:15.00
Max.   :20.00
```

- **Session 3 Box plot for each company and variables**

The following section explains what the box plot for each company and variables is.

```
> boxplot(`Name of company`,`Turnover (£ M)`,`Production rate/day`,`
Machining flexibility (%)`,`Operation agility( %)`,`Machine idle time (%)`,
`Annual inventory cost (£1000s)`,`ontime delivery (yes -1 or no-0)`,`Reject rate (%)`
,`Resource utilization (%)`,`Total production lead time( in days)`
+ ;

> attach(Cloud_FrameworkAS_newF2)
> plot(`Name of company`,`Turnover (£ M)`)
Warning message:
In xy.coords(x, y, xlabel, ylabel, log) : NAs introduced by coercion
> plot(`Production rate/day`,`Machine idle time (%)`)
> plot(`Production rate/day`,`Machine idle time (%)`,`Name of company`)
Error in plot.xy(xy, type, ...) : invalid plot type
> plot(`Production rate/day`,`Machine idle time (%)`,`Annual inventory cost
```

```
(£1000s)`,`Reject rate (%)`)
Error in plot.window(...) : invalid 'xlim' value
> boxplot(`Name of company`,`Turnover (£ M)`)
Error in x[floor(d)] + x[ceiling(d)] :
  non-numeric argument to binary operator
> boxplot(`Name of company`~ `Turnover (£ M)`)
Error in x[floor(d)] + x[ceiling(d)] :
  non-numeric argument to binary operator
> boxplot(`Turnover (£ M)`,`Machine set up time (min/hr)`)
> boxplot(`Turnover (£ M)`,`Machine set up time (min/hr)`,`Annual inventory
cost (£1000s)`,`Reject rate (%)`,`Resource utilization (%)`,`Total production
 lead time( in days)`)
```

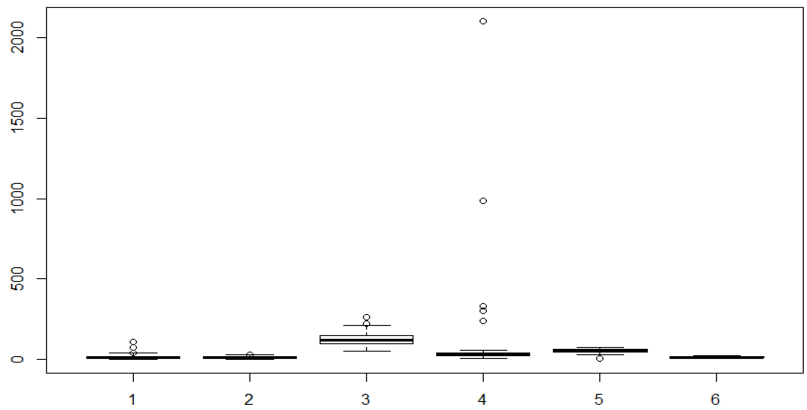

Fig 10. 12 Box plot for each attribute

Figure 10.12 shows the minimum and maximum values of each attributes for each virtual company. Summary of Box plots are shown for each company.

```
> head(Cloud_FrameworkAS_newF2)
# A tibble: 6 × 14
 `Name of company` `No of workers = >100` `Turnover (£ M) ` `Production rate/day` `Machining flexibi
lity (%) ` `Operation agility (%) `
```

	<chr>	<chr>	<dbl>	<dbl>	<dbl>	<dbl>
1	BCS	Yes	12.5	2000	60	25.0
2	AKN	No	2.0	200	50	40.0
3	KKC	Yes	5.0	500	65	30.3
4	CMN	Yes	4.0	200	65	19.0
5	RUS	Yes	1.0	50	50	12.0
6	PEN	No	2.0	5	35	18.0

Fig 10. 13 Details of all the variables are analysed

```
# ... with 8 more variables: `Machine idle time (%)` <dbl>, `Breakdown time (%)` <dbl>, `Machine set up
time (min/hr)` <dbl>, `Annual
```

inventory cost (£1000s)` <dbl>, `ontime delivery (yes -1 or no-0)` <dbl>, `Reject rate (%)` <dbl>, `Resource utilization (%)` <dbl>,
`Total production lead time( in days)` <dbl>
> attach(Cloud_FrameworkAS_newF2)
> boxplot(`Turnover (£ M)`~ `Name of company`)

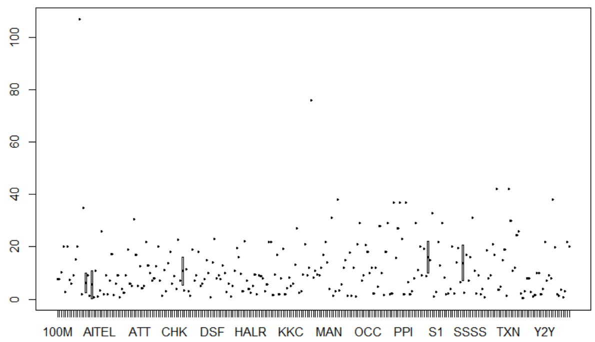

Fig 10. 14 Showing Box plot of companies against turnover

> boxplot(`Turnover (£ M)`~ `Name of company`)
> boxplot(`ontime delivery (yes -1 or no-0)`~ `Name of company`)

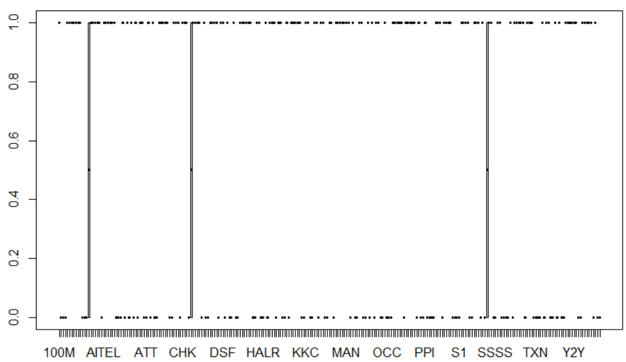

Fig 10. 15 Box plot companies against time delivery

> boxplot(formula = `Turnover (£ M)`~ `Name of company`)

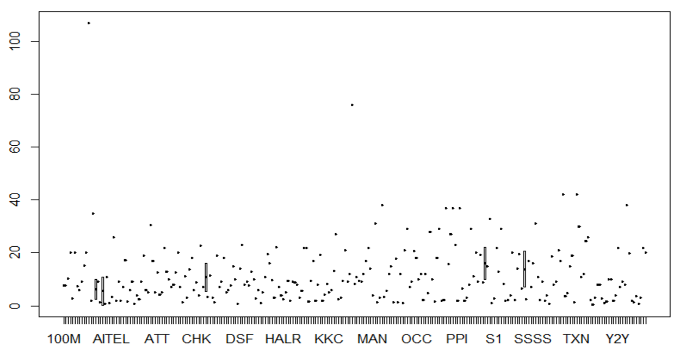

Fig 10. 16 Box plot showing companies against turnover

> hist(x=`Turnover (£ M)`)

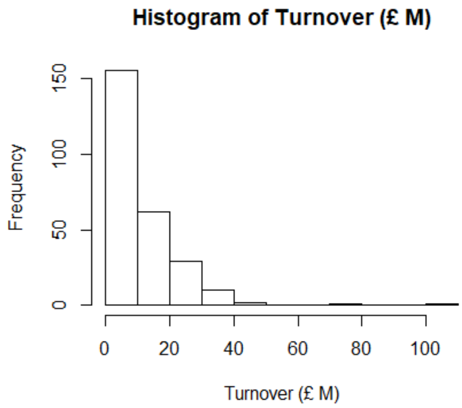

Fig 10. 17 Frequency of occurrence of different turnover of each company

```
> barplot(`Machine set up time (min/hr)`)
```

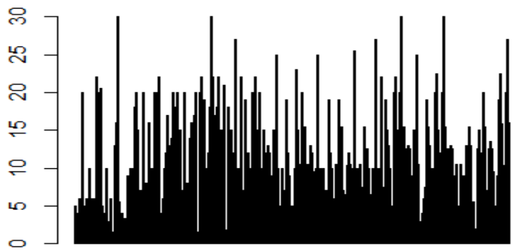

Fig 10. 18 correlation between production rates against turnover

```
> cor(`Turnover (£ M)`,`Production rate/day`,method = c("pearson"))
[1] 0.03262332
> plot(`Turnover (£ M)`,`Production rate/day`)
```

The Fig 10.18 explains the correlation between the two parameters i.e., production rates and turnover. This correlation is one of the various sets of combination of parameters so as to find the best combination which would contribute to the improvement of a manufacturing performance.

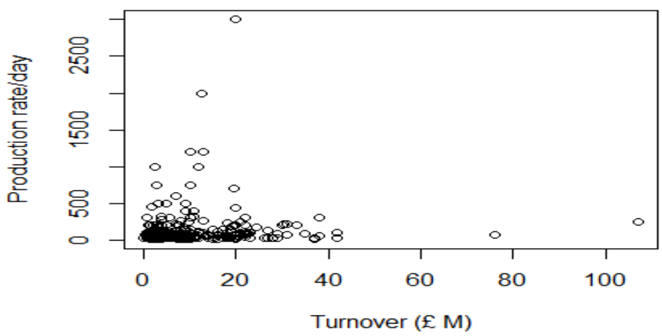

Fig 10. 19 Scatter plot matrix for production rate/day against turnover

The scatterplot matrix, which is similar to the correlation matrix, uses the command belo w.

```
> pairs(formula=~`Turnover (£ M)`+`Production rate/day`+`Machining flexibility (%)`+ `Operation agilit y( %)`+`Machine idle time (%)`)
```

- **Session 4 Scatter box**

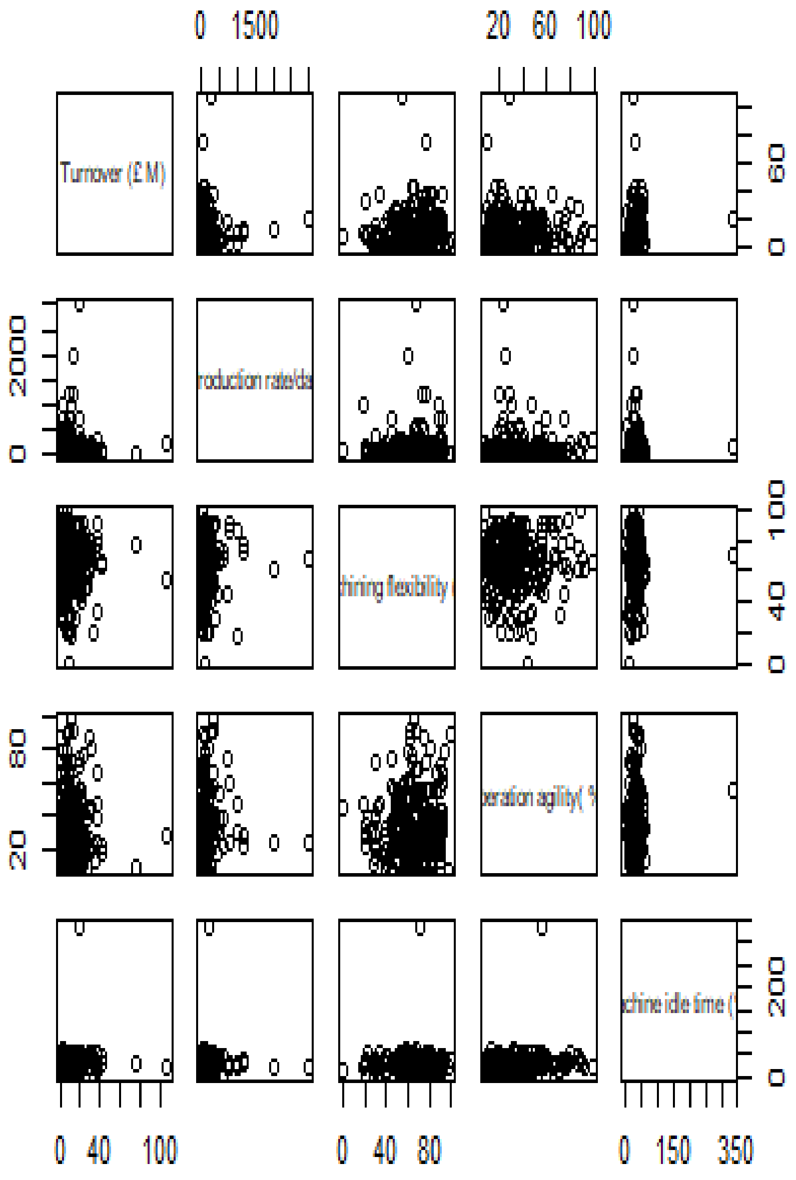

Fig 10. 20 Scatter box plot for machining flexibility, operation agility, breakdown time, resource unitization and total production lead time

```
> library(plot3D)
> library(plotly)
> pairs(formula= ~`Machining flexibility (%)`+ `Operation agility( %)`+`Breakdown time (%)`+`Resource utilization (%)`+`Total production lead time( in days)`)
```

- **Session 5 Correlation test**

The next step of the analysis is the correlation test

Starting the system for **Correlation test**

This was followed by performing the correlation test as follows:

```
> View(Cloud_FrameworkAS_newF2)
> install.packages("dplyr")
```

```
package 'dplyr' successfully unpacked and MD5 sums checked
The downloaded binary packages are in
C:\Users\Owner\AppData\Local\Temp\RtmpOIfqC5\downloaded_packages
> library("dplyr")
> library(readxl)
> library(cluster)
> library(ggplot2)
> library(tidyr)
> library(fpc)
> library(plotly)
> library(NbClust)
> library(plot3D)
> attach(Cloud_FrameworkAS_newF2)
```

```
> cor.test( `Machining flexibility (%)`, `Operation agility( %)`  ,method = "pearson", conf.level = 0.
95)
```

Pearson's product-moment correlation

```
data:  Machining flexibility (%) and Operation agility( %)
t = 0.73166, df = 258, p-value = 0.465
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 -0.0765734  0.1662376
sample estimates:
      cor 0.04550416
> cor.test( `Operation agility( %)` , `Breakdown time (%)` ,method = "pearson", conf.level = 0.95)
```

Pearson's product-moment correlation

```
data:  Operation agility( %) and Breakdown time (%)
t = -0.8994, df = 258, p-value = 0.3693
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 -0.17636068  0.06619741
sample estimates:
       cor  -0.05590648
> cor.test( `Machining flexibility (%)`, `Breakdown time (%)` ,method = "pearson", conf.level = 0.9
5)
```

Pearson's product-moment correlation

data: **Machining flexibility (%) and Breakdown time (%)**
t = 1.4252, df = 258, p-value = 0.1553
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
-0.0336361 0.2077987
sample estimates:
cor 0.08837921

> **cor.test(`Machining flexibility (%)`, `Resource utilization (%)`** ,method = "pearson", conf.level = 0.95)

Pearson's product-moment correlation

data: **Machining flexibility (%) and Resource utilization (%)**
t = 2.1506, df = 258, p-value = 0.03244
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
0.01123141 0.25031634
sample estimates:
cor 0.1327038

> cor.test(`Machining flexibility (%)`, `Total production lead time( in days)` ,method = "pearson", conf.level = 0.95)

Pearson's product-moment correlation

data: **Machining flexibility (%) and Total production lead time(in days)**
t = -0.028319, df = 258, p-value = 0.9774
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
-0.1233902 0.1199163
sample estimates:
cor -0.001763042

The results from the Pearson gives *cor* value = 0.937 and for Spearman gives rho value of 0.93. Both results show strong positive correlation between the machining flexibility and production lead times. This is confirmed in the scatterplot matrix Fig 10.20.

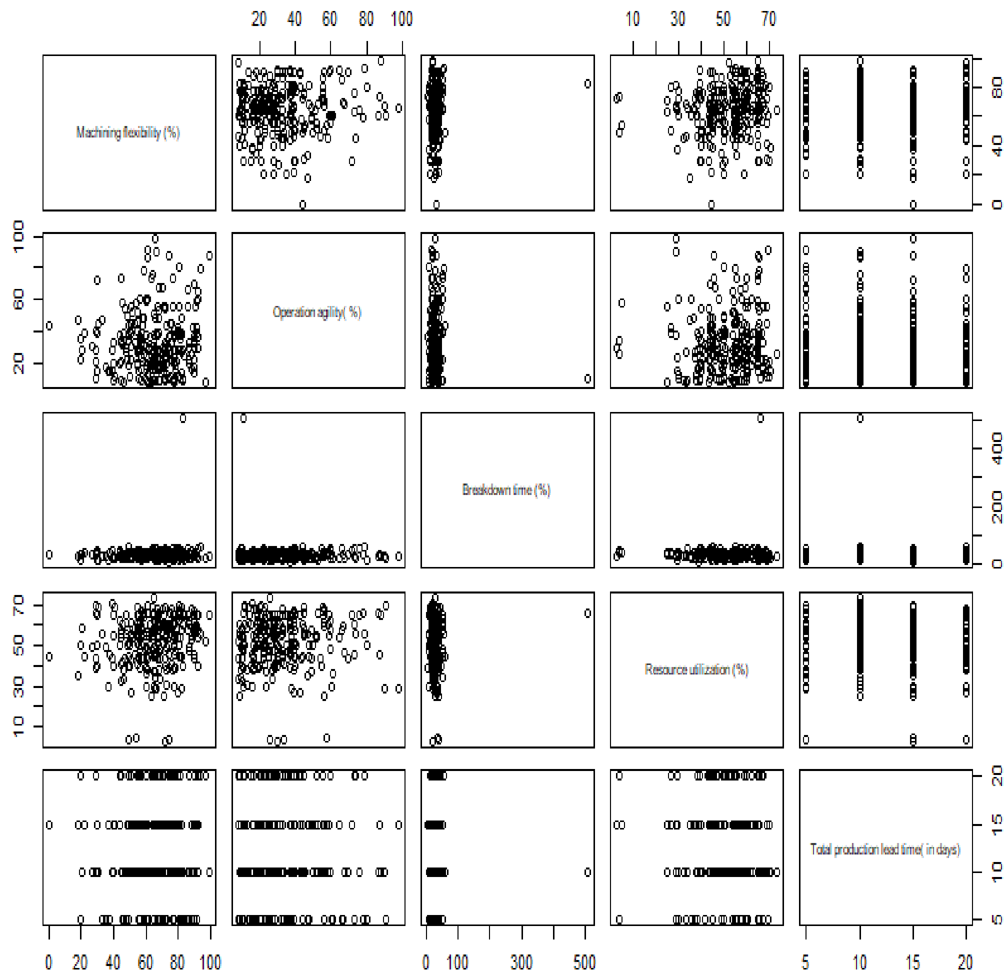

Fig 10. 21 Correlation test for machining flexibility, operation agility, breakdown time, resource unitization and total production lead time

Session 6 Linear model using Linear Regression and Multiple Regression

Session 6 – Linear Regression:

For Linear Regression comparison two LR models were conducted as follows:

- Linear Regression for machining flexibility
- Linear Regression for operator agility

```
model1<-lm(`Machining flexibility (%)`~ `Operation agility( %)`)
summary(model1)
plot(model1)
```

```
> model1<-lm(`Machining flexibility (%)`~ `Operation agility( %)`)
> plot(model1)
> model1<-lm(`Machining flexibility (%)`~ `Operation agility( %)`)
> summary(model1)
Call:
lm(formula = `Machining flexibility (%)` ~ `Operation agility( %)`)
Residuals:
    Min      1Q  Median      3Q     Max
-65.075  -8.994   1.376  12.201  33.437
Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)             63.23044    2.15439  29.350   <2e-16 ***
`Operation agility( %)`  0.04155    0.05679   0.732    0.465
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 16.92 on 258 degrees of freedom
Multiple R-squared:  0.002071,    Adjusted R-squared:  -0.001797
F-statistic: 0.5353 on 1 and 258 DF, p-value: 0.465
> plot(model1)
Hit <Return> to see next plot:
```

Analysis shows that the significance is between 0.001 and 0.05 which indicates that there is a strong relationship between the machining flexibility and operation agility and acceptable.

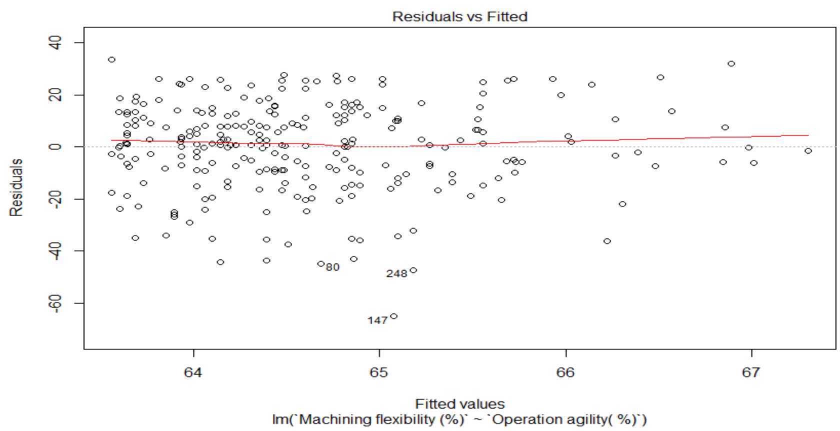

Fig 10. 22 Regression analysis for machining flexibility and operation agility

Output measures from the analysis of liner regression between machining flexibility and operation agility indicates a strong correlation between the two variables.

Deviation

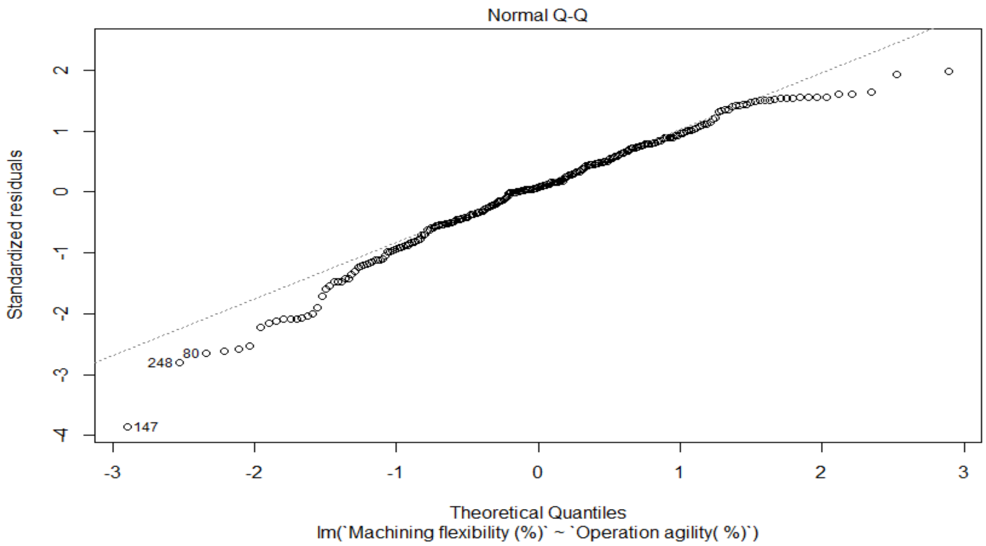

Fig 10. 23 Correlation between machining flexibility and operation agility (normal Q-Q)

Fig 10.23 shows linear regression curve of the machining flexibility and operation agility. It also shows the deviation from normal curve is very small and negligible. Fig 10.24 shows how the data points are distributed in terms of location relating to the data set.

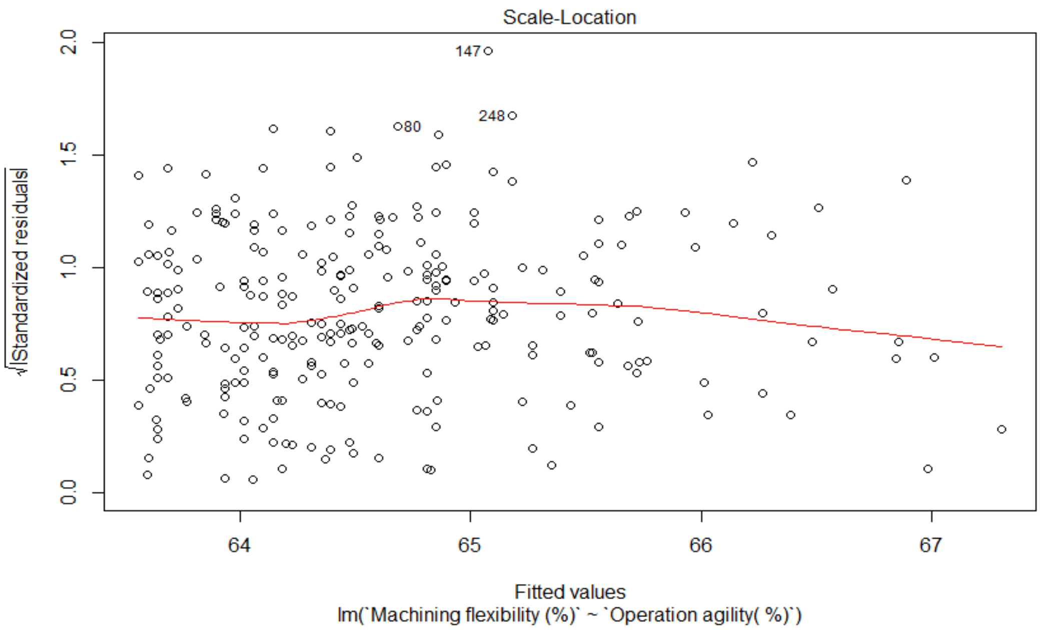

Fig 10. 24 Correlation between machining flexibility and operation agility (scale-location)

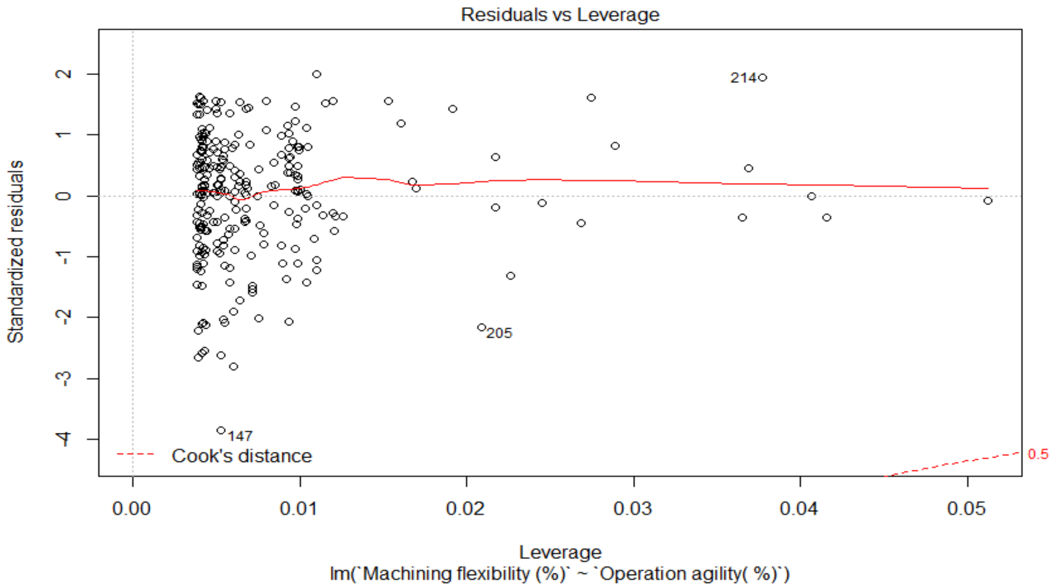

Fig 10. 25 Correlation between machining flexibility and operation agility (residual vs fitted)

- **Session 6 -Multiple Regression**

This Multiple Regression analysis for attributes used for attributes against the other Labels and variables in the dataset.

The following figures show multiple regression analysis for attributes used for attributes against the other labels and variables in the dataset.

Multiple regression between machining flexibility and operation agility show distribution of machining flexibility. From this curve an equation is generated using the trend line techniques to the relationship between machining flexibility and various data points.

The equation is $R^2 – 0.004\ R^2 – 0.01148$ where R^2 the machining flexibility.

Fig 10.26 confirms the strong relationship between the two parameters Machine flexibility and Operational Agility.

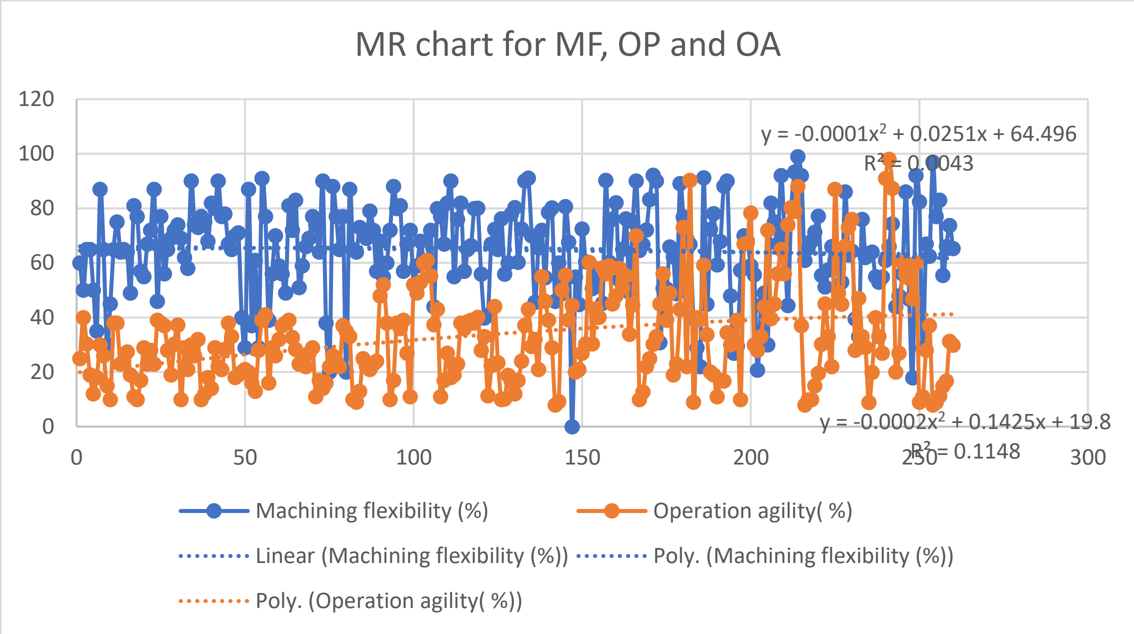

Fig 10. 26 Multiple Regression chart for MF, OP and OA

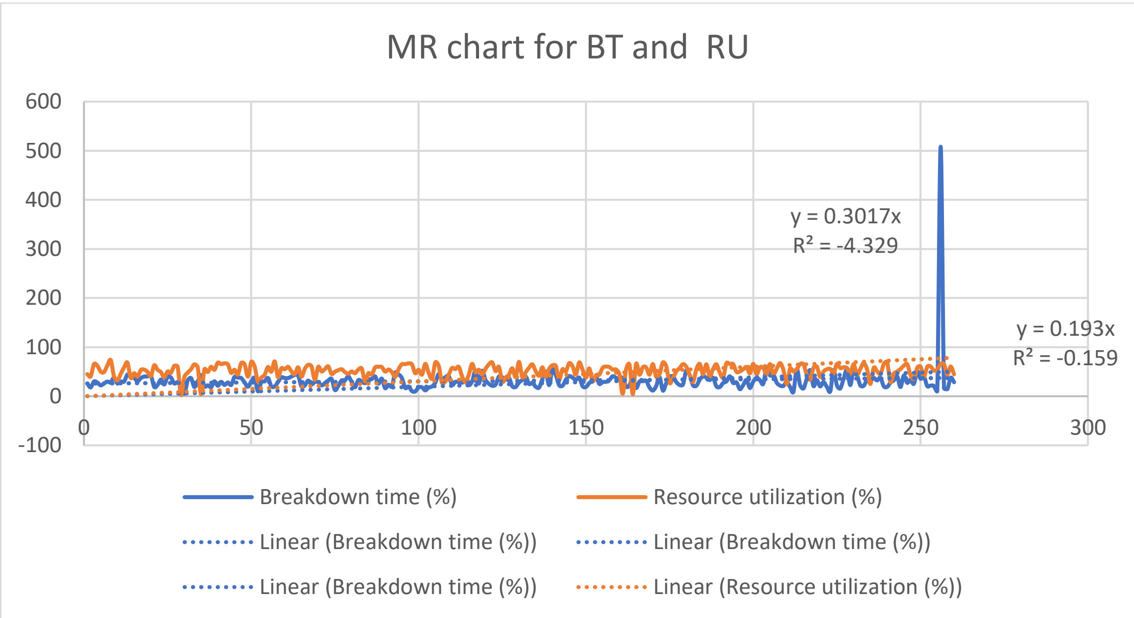

Fig 10. 27 Multiple Regression chart for BT and RU

Figure 10.27 shows a strong relationship between breakdown time and resource utilization.

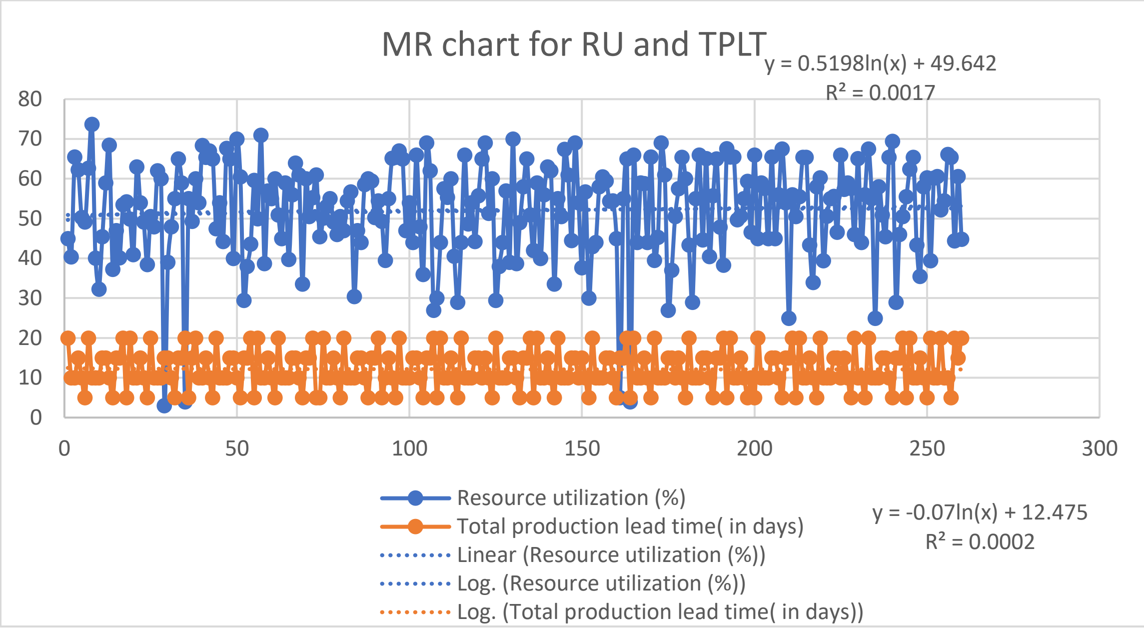

Fig 10. 28 Multiple Regression chart for RU and TPLT

Fig 10.28 indicates a good relationship between resource utilization and production lead time.

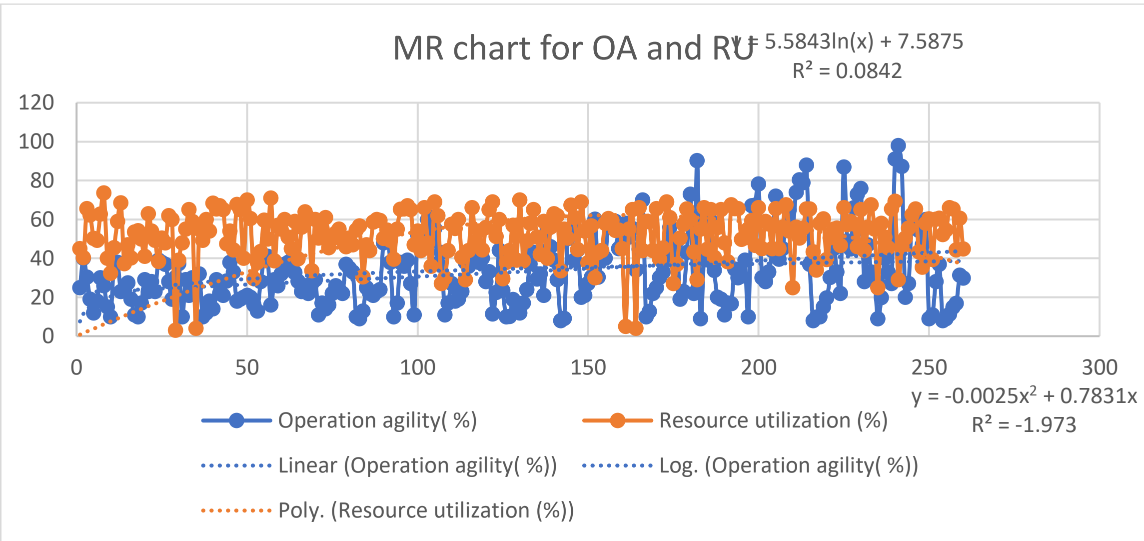

Fig 10. 29 Multiple Regression chart for OP and RU

Figure 10.29 show a strong correlation between operation agility and resource utilization.

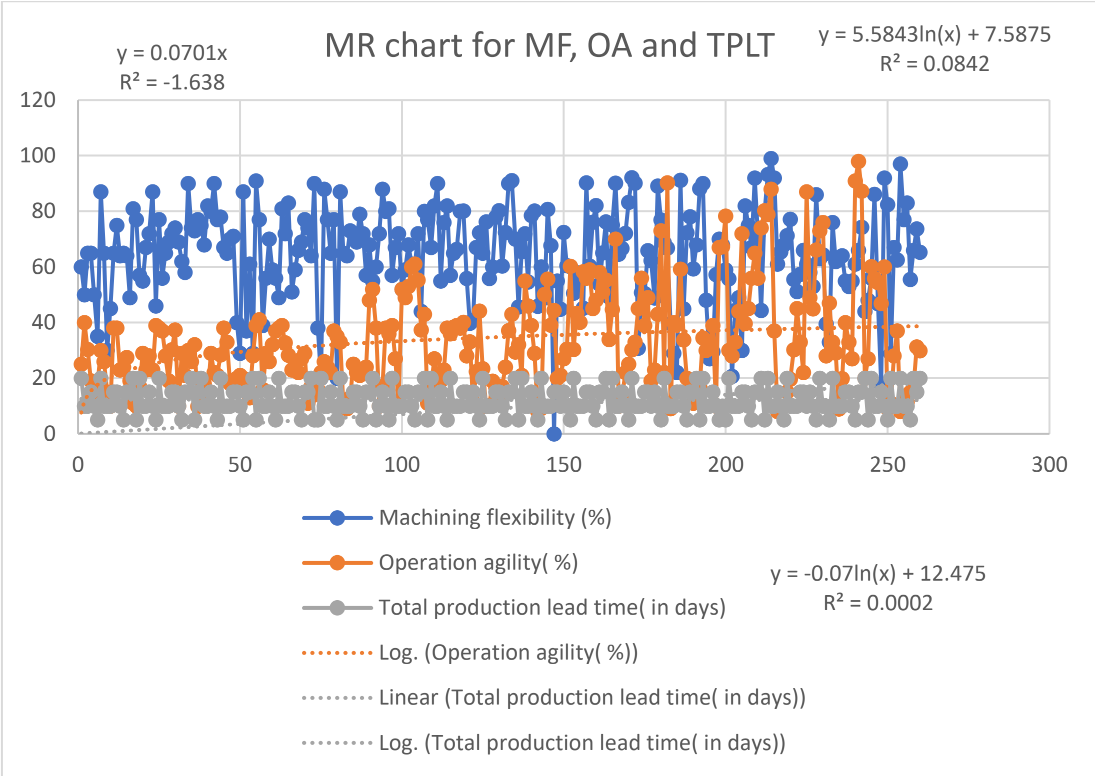

Fig 10. 30 Multiple Regression chart for MF, OA and TPLT

- **Session 7**

This section of the simulation analyses of output measures for multiple regression for operation agility and production lead time.

```
> View(Cloud_FrameworkAS_newF2)
> attach(Cloud_FrameworkAS_newF2)
> model23<-lm(`Operation agility( %)`~ `Total production lead time( in days)`)
> summary(model23)

Call:
lm(formula = `Operation agility( %)` ~ `Total production lead time( in days)`)

Residuals:
    Min      1Q  Median      3Q     Max
-26.209 -13.708  -3.358   7.805  65.292

Coefficients:
                                       Estimate Std. Error t value Pr(>|t|)
(Intercept)                             34.9602     3.1749  11.012   <2e-16 ***
`Total production lead time( in days)`  -0.1502     0.2435  -0.617    0.538
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 18.53 on 258 degrees of freedom
Multiple R-squared:  0.001472,     Adjusted R-squared:  -0.002398
F-statistic: 0.3804 on 1 and 258 DF,  p-value: 0.538

> plot(model23)
```

Hit <Return> to see next plot:
Hit <Return> to see next plot:
Hit <Return> to see next plot:
Hit <Return> to see next plot:

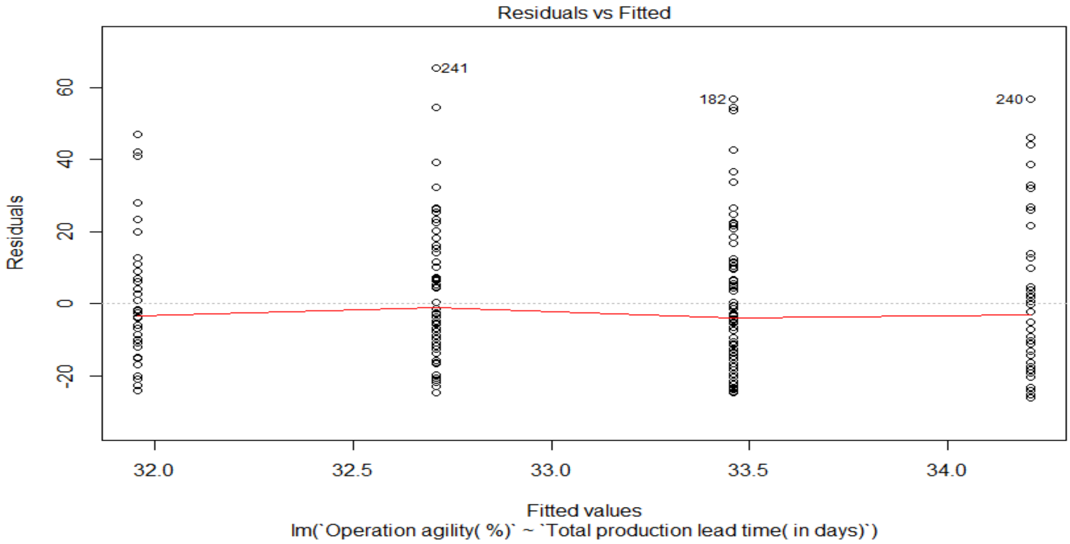

Fig 10. 31 Residual vs fitted for OA and TPLT

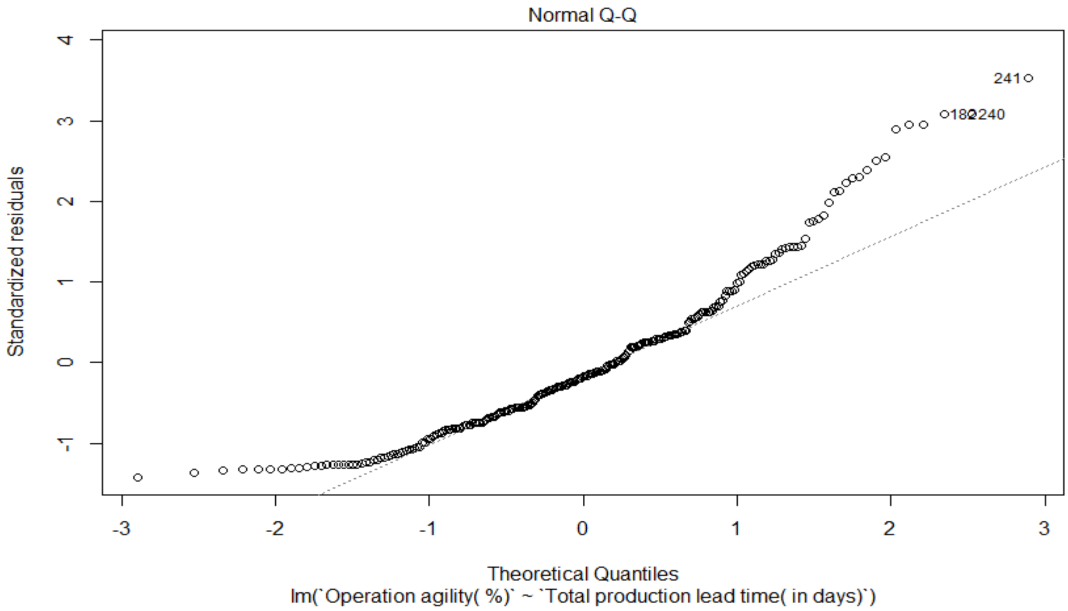

Fig 10. 32 Standardized residuals vs Theoretical quantities between OA ad TPLT

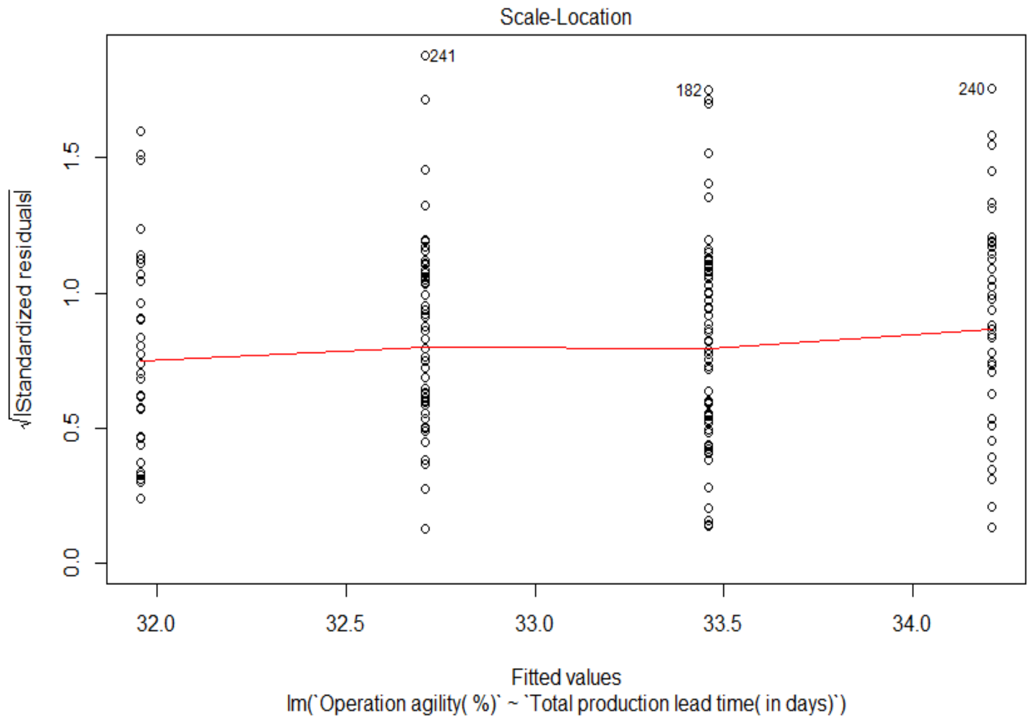

Fig 10. 33 Scale- location: OA and TPLT

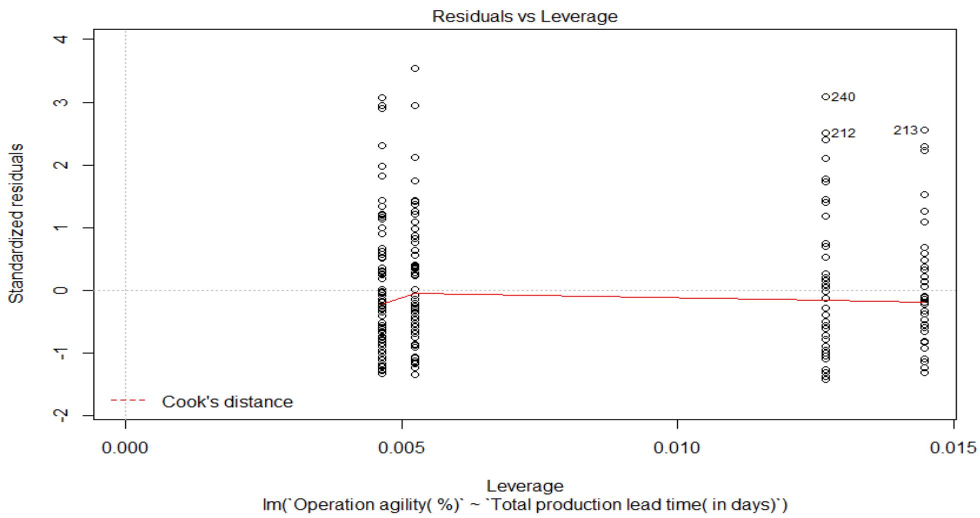

Fig 10. 34 Residuals vs Leverage of OA and TPLT

```
> hist(model23$residuals)
> rug(model23$residuals)
```

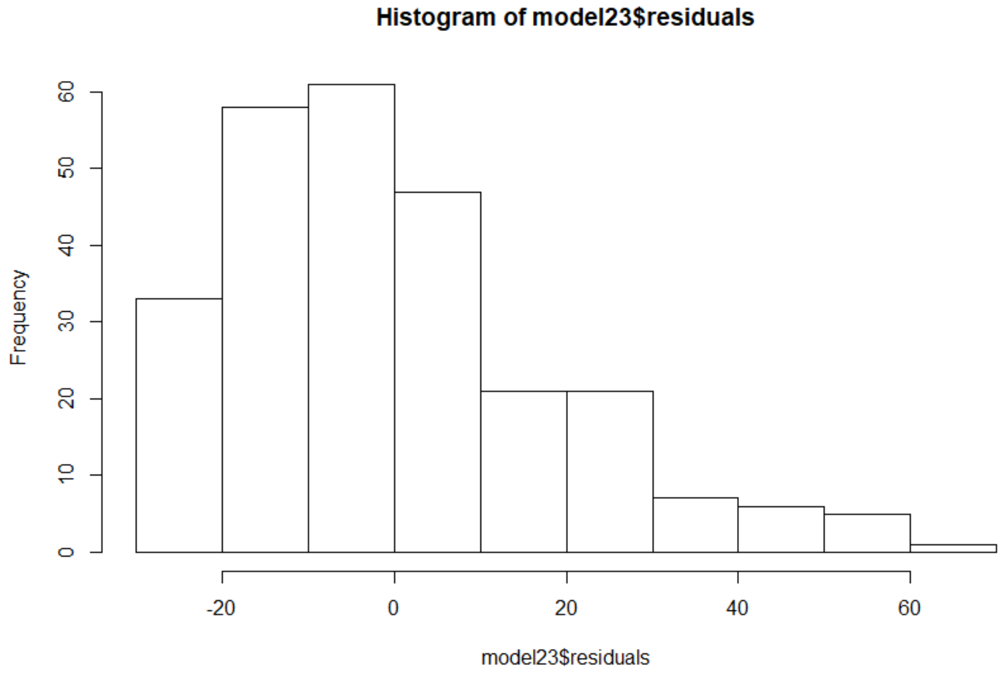

Fig 10. 35 Histogram of model23 $ residuals

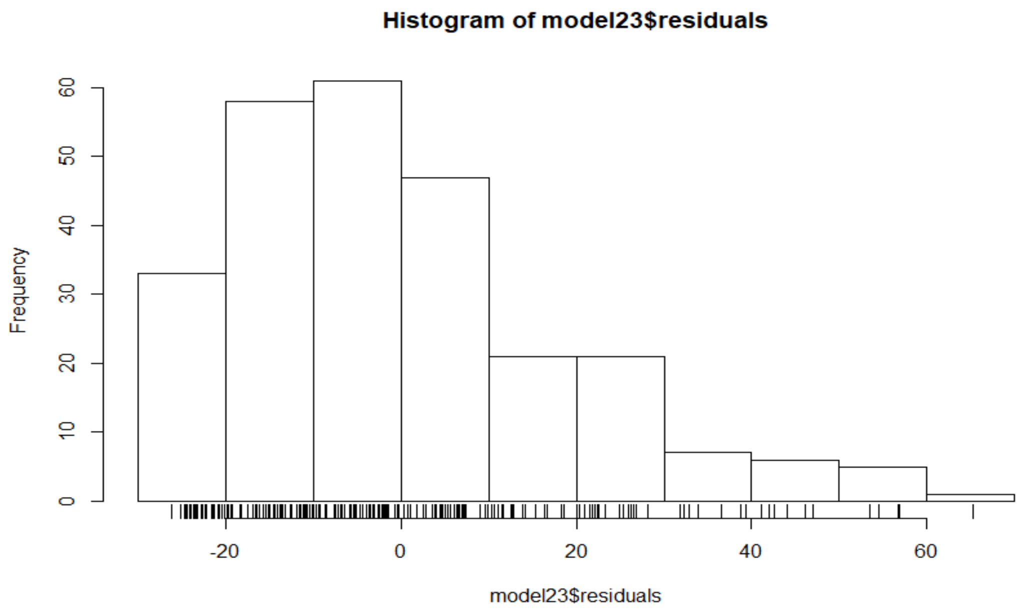

Fig 10. 36 Histogram of model23 $ residuals

```
> model24<-lm(`ontime delivery (yes -1 or no-0)`~ `Operation agility( %)`+
`Machining flexibility (%)`+ `Breakdown time (%)`)
> summary(model24)

Call:
lm(formula = `ontime delivery (yes -1 or no-0)` ~ `Operation agility( %)` +
    `Machining flexibility (%)` + `Breakdown time (%)`)

Residuals:
    Min      1Q  Median      3Q     Max
-0.7303 -0.5665  0.3245  0.4176  0.5634

Coefficients:
                              Estimate Std. Error t value Pr(>|t|)
(Intercept)                 0.756960   0.131708   5.747 2.57e-08 ***
`Operation agility( %)`      0.001347   0.001645   0.819   0.4137
`Machining flexibility (%)` -0.003647   0.001806  -2.020   0.0444 *
`Breakdown time (%)`         0.001076   0.000975   1.104   0.2706
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.4886 on 256 degrees of freedom
Multiple R-squared:  0.02057,	Adjusted R-squared:  0.009095
F-statistic: 1.792 on 3 and 256 DF,  p-value: 0.149

> plot(model24)
Hit <Return> to see next plot:
```

Hit <Return> to see next plot:


```
> model24<-lm(`ontime delivery (yes -1 or no-0)`~ `Operation agility( %)`+
`Machining flexibility (%)`+ `Breakdown time (%)`)
> summary(model24)

Call:
lm(formula = `ontime delivery (yes -1 or no-0)` ~ `Operation agility( %)` +
    `Machining flexibility (%)` + `Breakdown time (%)`)

Residuals:
    Min      1Q  Median      3Q     Max
-0.7303 -0.5665  0.3245  0.4176  0.5634

Coefficients:
                              Estimate Std. Error t value Pr(>|t|)
(Intercept)                 0.756960   0.131708   5.747 2.57e-08 ***
`Operation agility( %)`      0.001347   0.001645   0.819   0.4137
`Machining flexibility (%)` -0.003647   0.001806  -2.020   0.0444 *
`Breakdown time (%)`         0.001076   0.000975   1.104   0.2706
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.4886 on 256 degrees of freedom
Multiple R-squared:  0.02057,	Adjusted R-squared:  0.009095
F-statistic: 1.792 on 3 and 256 DF,  p-value: 0.149

> plot(model24)
Hit <Return> to see next plot:
```

Hit <Return> to see next plot:
Hit <Return> to see next plot:
Hit <Return> to see next plot:

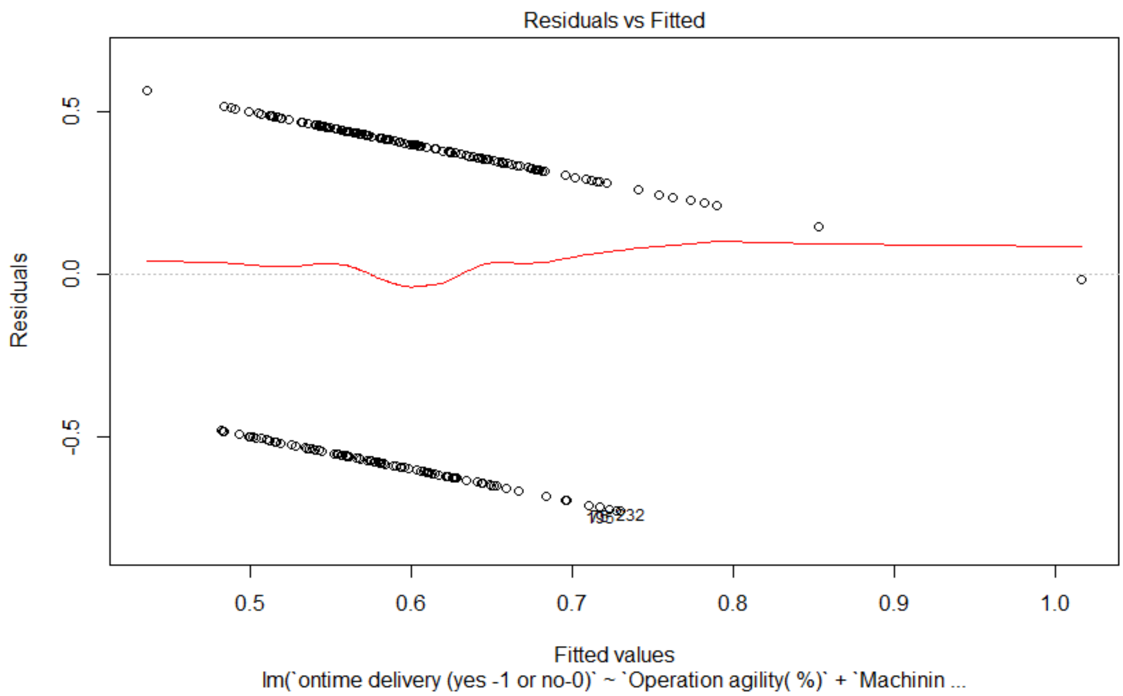

Fig 10. 37 Residual vs fitted of model 24

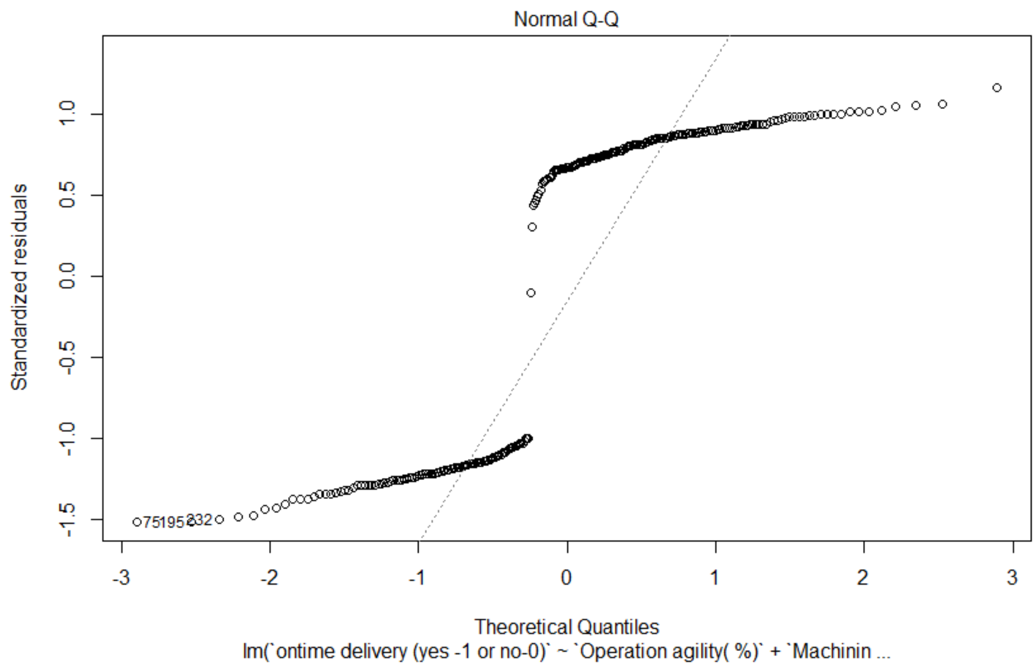

Fig 10. 38 Normal Q-Q of model 24

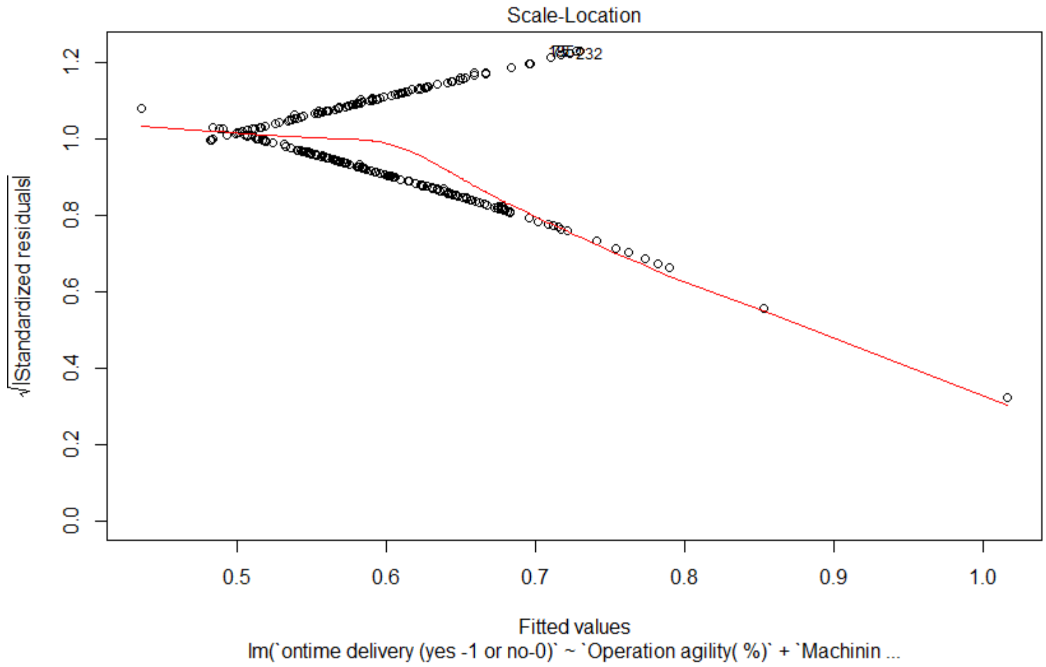

Fig 10. 39 Scale location of model 24

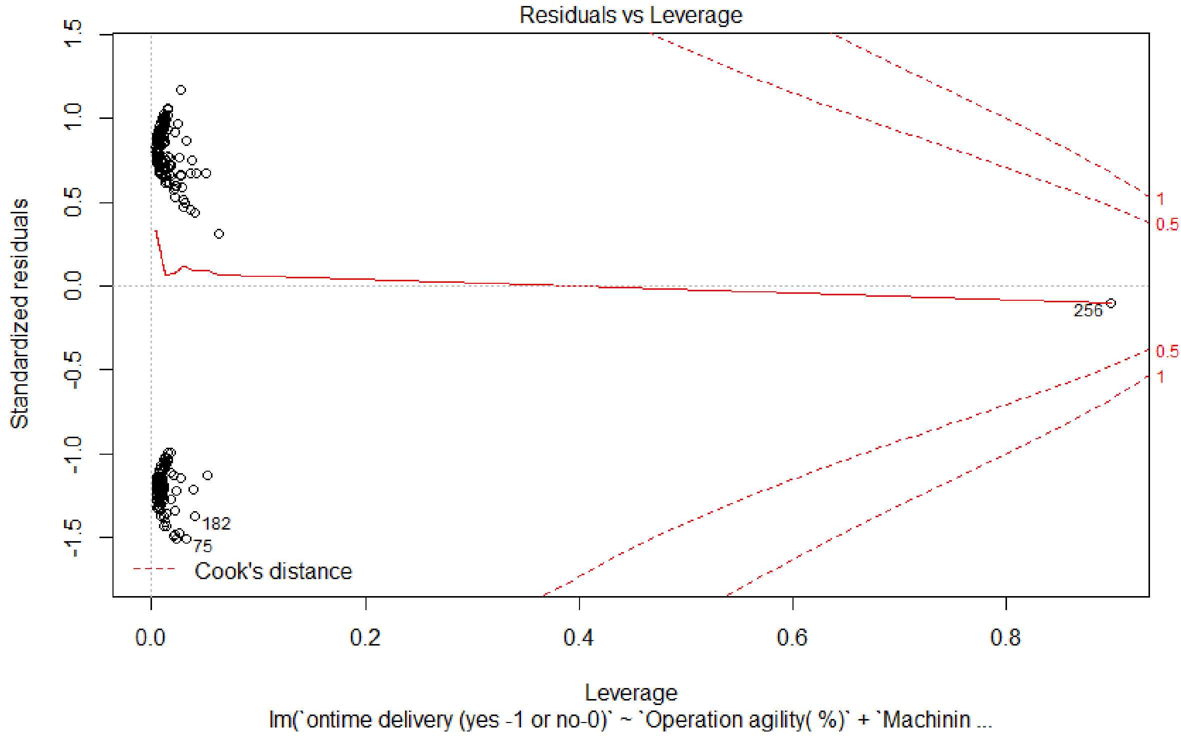

Fig 10. 40 Residuals vs Leverage of model 24

```
> hist(model24$residuals)
```

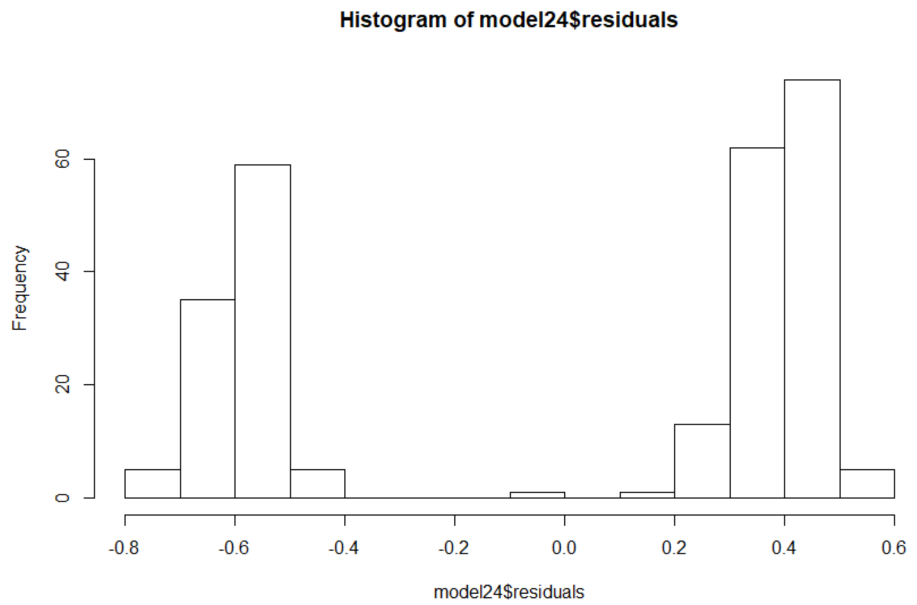

Fig 10. 41 Histogram of model 24 $ residuals

```
> rug(model24$residuals)
```

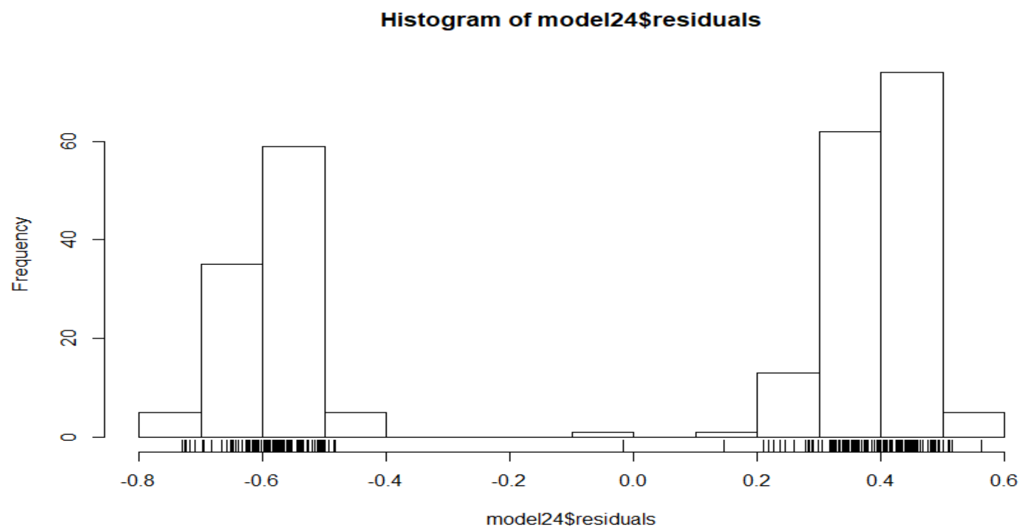

Fig 10. 42 Histogram of model 24 $ residuals

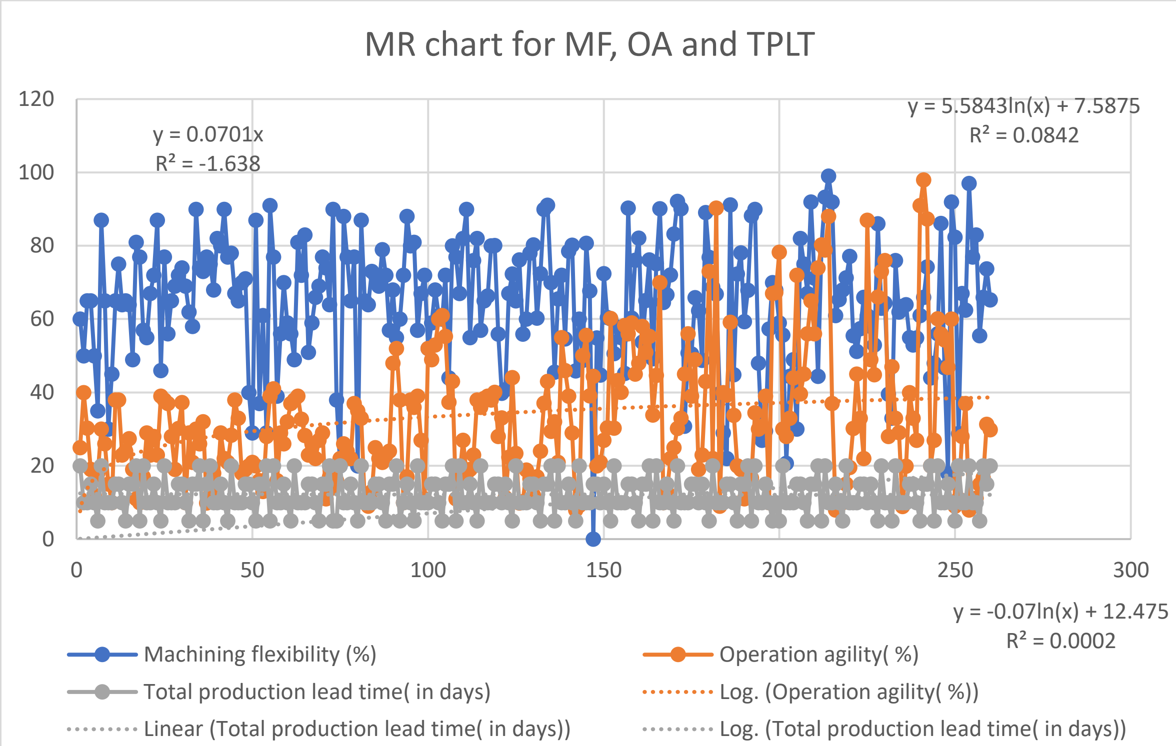

Fig 10.30 MR chart for MF, OA and TPLT

10 manufacturing variables were used in the analysis. Several combinations of variables were examined to identify the appropriate set of parameters that would improve the overall manufacturing performance including on-time delivery. Amongst the tests that were carried out on different combination of variables), output in Fig 10.30, shows that the three parameters i.e. machining flexibility, operational agility and total production lead time have strong correlation between them and can have a significant effect on overall manufacturing performance. These variables are paramount in optimizing manufacturing operations by enabling to achieve on-time delivery.

10.3. 3 Discussion and Conclusion

Statistical analysis performed in the validation study identified the best possible combination of variables that will contribute to the improvement of the production operation and overall manufacturing performance. Through simulation study, using WITNESS, ten manufacturing process variables were identified as the prime candidates to enhance manufacturing performance. These parameters are: machine idle time, break down time, inventory cost, resource utilization, total production lead time, resource utilization, operational agility, machining flexibility, total production lead time were considered for this analysis. Analysis in Fig 10.30 shows that machining flexibility (MF), operational agility (OA) and total production lead-time (TPLT), have strong correlation can have significant effect in improving the manufacturing performance. Several combinations of variables were examined to identify the most suitable set of parameters that would enhance the manufacturing performance amongst these, machining flexibility, operational agility and total production lead time were identified as critical parameters to optimise manufacturing performance. Hence, it can be concluded that the proposed CEMM consider these variables during the implementation.

PART VI- CONCLUSION

Chapter 11
Conclusion and further work

11.1 Introduction

Although manufacturers benefit from numerous latest manufacturing technologies, there are still many difficulties and problems the optimum manufacturing performance in many SMEs. Examples of these problems include sharing of manufacturing resources, where the resources are centralised into the network but cannot be distributed through the network. This is due to a lack of manufacturing services management in the network and the inability to access the manufacturing hard resources in the manufacturing network because of the complications involved in sharing hard resources in real time. Another issue is the difficulty in knowledge sharing between manufacturing firms, customers, suppliers and partners due to security and compliance issues and the management of large amount of data securely in the complex, manufacturing collaborative environment.

Cloud manufacturing is one of the emerging that has a significant impact on manufacturing industry by enabling the sharing of manufacturing resources and capabilities as services and fostering collaboration. However, applying new and complex technologies in the manufacturing sector can create unknown and unpredictable complications. The concept of cloud manufacturing is to integrate existing manufacturing technologies and computing technologies to distribute manufacturing resources and capabilities between manufacturing units and divisions, which are geographically apart from each other. Cloud service provider identifies physical resources and manufacturing capabilities into a virtualized resource pool by using technologies such as cloud computing, IoT and provide those resources and capabilities as services to the consumer.

This research examines how to improve manufacturing flexibility and investigates how flexibility could be enhanced to enhance manufacturing operations through the application of CEMM. CEMM would provide services on-demand at lower cost and would accelerate the development of an intelligently networked, service-oriented, distributed manufacturing.

Critical success factors were identified from the literature review which forms the basis for the development of CEMM which emphasises on elastic capability of manufacturing to optimise the overall manufacturing performance of a SME. The study also provided specific considerations in undertaking technology integration in manufacturing environment and highlighted the need to reduce the impediments to facilitate successful technology transfer cooperation. This was achieved by addressing the issues that would arise when an attempt to realise the elastic capability of the cloud manufacturing system. The decision makers ranked these issues and thus they can concentrate and address those issues before proceeding with the CEMM. The study also presented insights into the way technology adoption decisions are made and factors that may influence the technology adoption through CEMM.

The proposed model was validated using simulation study and statistical analysis to study the relationships between various set of manufacturing capabilities and process variables to improve manufacturing flexibility and overall performance. Analysis of the results showed that adopting CEMM could yield many benefits to the organisation including improving the overall manufacturing performance, through efficient resource utilization, which in turn improves operational agility of a manufacturing firm.

11.2 Contribution to knowledge

Integrating complex technologies and networks in the manufacturing environment can create many unpredictable situations and unknown problems and the key characteristic of cloud computing called 'elasticity' may not be achieved in real time. If the elasticity is not achieved, adoption of cloud manufacturing may not yield much benefit for the manufacturing firms. A Cloud based elastic manufacturing (CEMM) which emphasizes on this elasticity assessment has been developed in this research that enables the sharing of manufacturing resources and capabilities as services and creating an efficient collaboration.

This research assesses the elastic capability by introducing an Elastic and Decision Support layer in the CEMM architecture. This research also introduces a tool to assess elasticity, which is considered to a unique contribution since none of the existing cloud-based manufacturing models emphasise the importance of elasticity in their architecture. Besides, CEMM enhances knowledge sharing between cross-functional units in manufacturing enterprises by integrating production control and management and buyer-supplier coordination. The components of CEMM provides a significant integration of concepts, and relationships and networked knowledge sharing in cloud manufacturing. Additionally, CEMM enhances the integration of existing manufacturing technologies and new computing technologies to distribute manufacturing resources and capabilities between manufacturing firms swiftly and empower collaboration.

11.3 Limitations of the study

The limitation of this study is that it has not been possible to assess the potential of the CEMM in a real time manufacturing environment as it involves a higher-level collaboration with the organisations due to time constrain and budget limitation. An empirical study could have provided more information and insight into the manufacturing operations and problems that SMEs experience in modern day. In order for CEMM to function effectively, a huge database must be maintained by a third-party service provider which may not be possible in the current business climate but feasible in the near future when problems and issues related to security, compliance are dealt with. The other dilemma is that, when companies from different parts of the world collaborate in manufacturing, it involves taxes and policies that each country approaches in different ways, and these issues must be addressed by the cloud service provider to mitigate potential risks associated with legality. The model CEMM only focussed on elasticity and the issues that are involved in realising elasticity, whereas there are many other aspects of cloud computing which need be assessed in the application of CEMM in real time manufacturing environment.

11.4 Further work

CEMM did not address knowledge-based system or intelligent data-base search strategy and other aspects to find suitable manufacturing resources in the cloud. This should be considered in the future model. Although CEMM achieved several tasks in supporting manufacturing activities, the research did not consider the specific agent-based manufacturing, computing architecture and business model of the companies. The specific requirements individual companies should be explored and serve as a benchmark for developing future CEMM systems. Further work should also consider the types of manufacturing functions that are suitable to migrate to CEMM.

11.5 Recommendations

- Many companies suffer inefficient networked manufacturing setting and needs essential technology to connect manufacturing resources to interact.
- It is recommended that manufacturing SMEs should consider investing of cloud adoption, as it is future of SMART manufacturing.
- Applying new and complex technologies and networks through cloud manufacturing in the manufacturing industry can create unknown and unpredictable situations leading to many uncertainties. In order to control manufacturing resources such as equipment, production cells, robots, workstation and assembly lines in CEMM systems effectively, it is imperative to monitor real-material movement, resource availability and capacity management of production resources, process planning, job scheduling, and job dispatching in real time. Therefore, cloud-based manufacturing system should have the capability to collect real-time data using IoT tools and techniques such as RFID.
- To assist users to find suitable manufacturing resources in the cloud, a cloud-based manufacturing model or system should provide an intelligent search engine to assist users' queries.
- To streamline workflow and improve business processes, a cloud-based manufacturing system should provide an online quoting engine to generate instant quotes based on manufacturing specifications.
- Companies moving towards cloud-based manufacturing should consider specific strategies or business models that should be used by service providers to CEMM.
- Before considering using CEMM, companies should identify the type of manufacturing services that are suitable to move to the cloud.

- Identify organisational and management issues that include the lifecycle of cloud manufacturing; assess the benefits of adopting cloud manufacturing.
- Investigate the standards for migrating into cloud manufacturing.

PART VII- References

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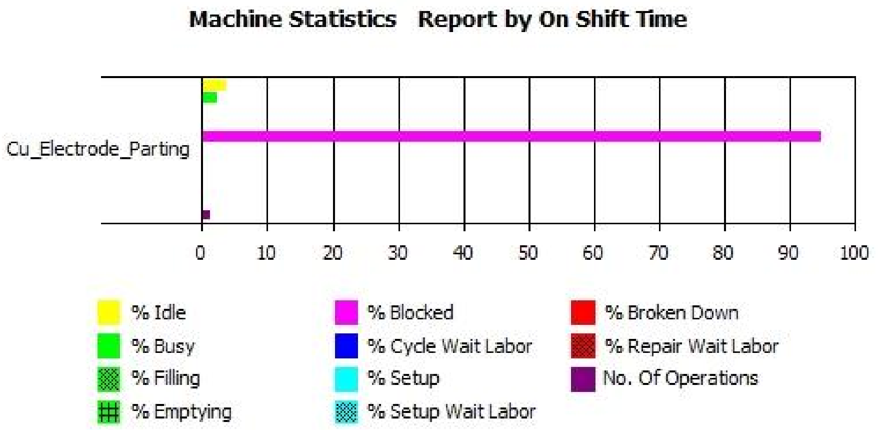
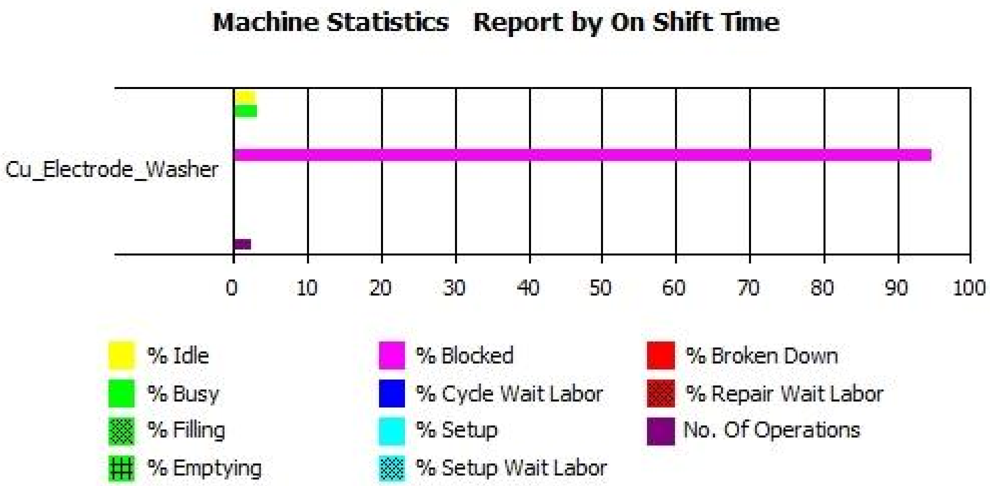
Part VIII - Appendices

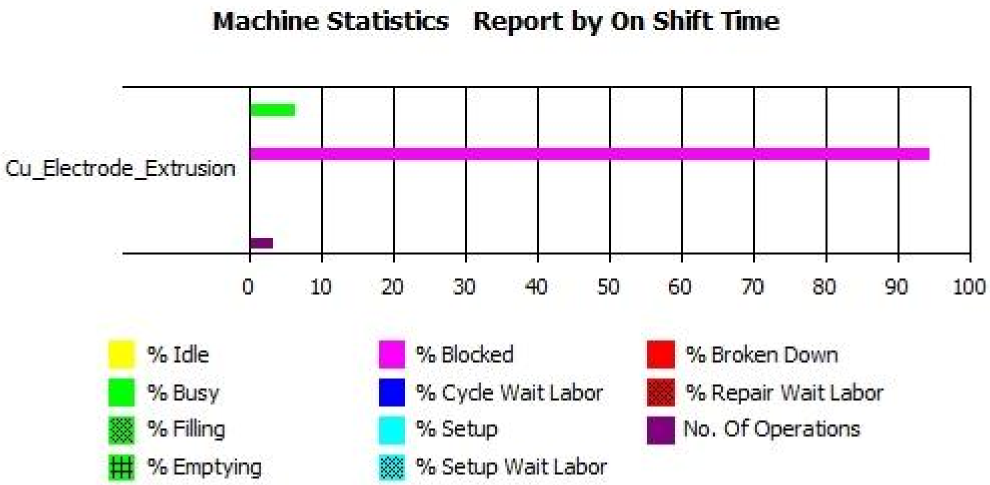
Appendix A: Machine statistics for 60 min production run



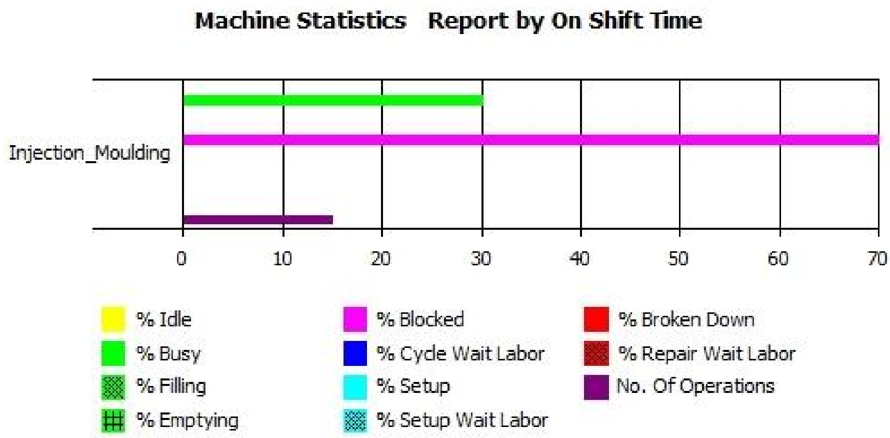
Machine statistics for Cu_Electrode_Parting



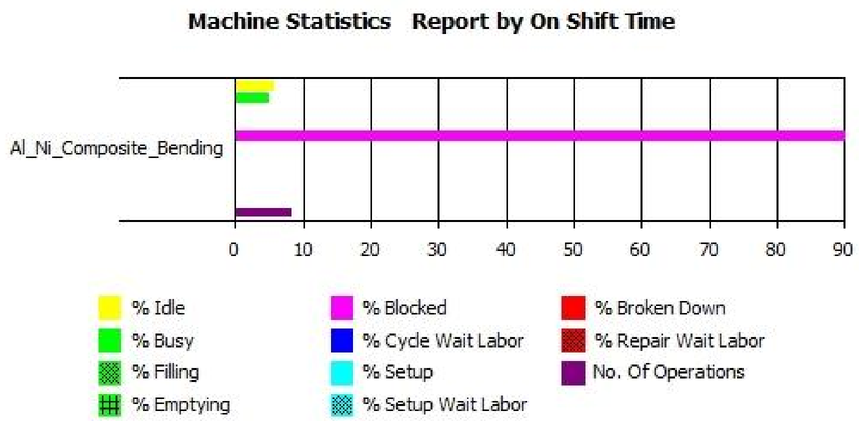
Machine statistics forCu_Electrode_Washer



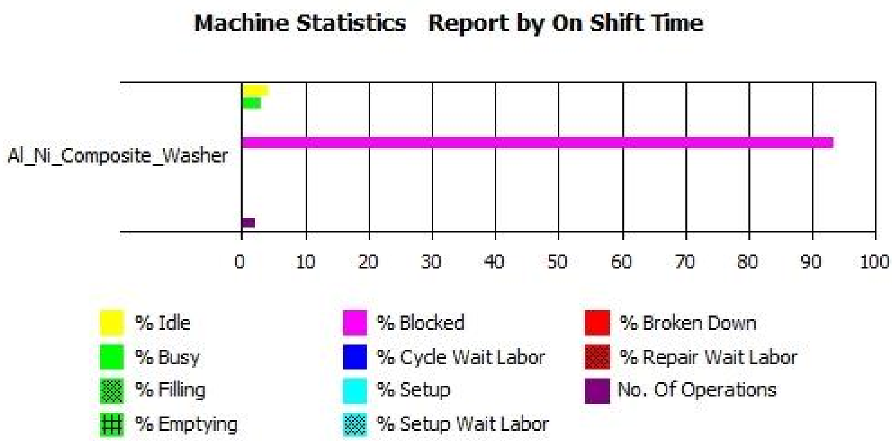
Machine statistics for Cu_Electrode_Extrusion



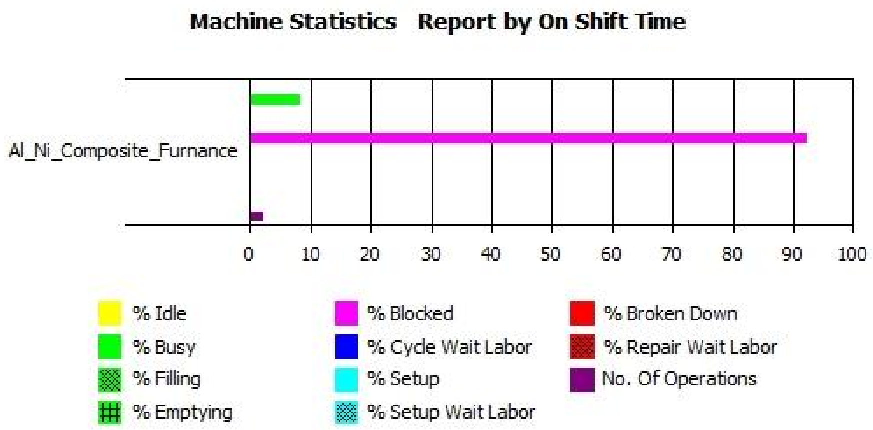
Machine statistics for Injection_Moulding



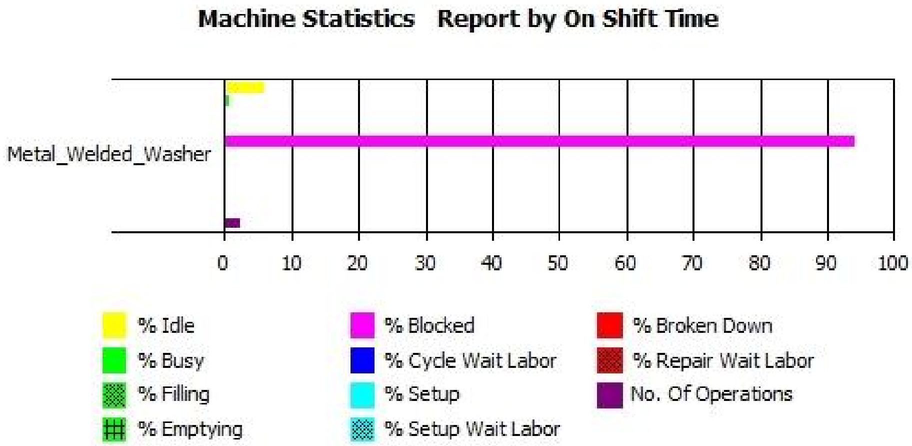
Machine statistics for Al_Ni_Composite_Bending



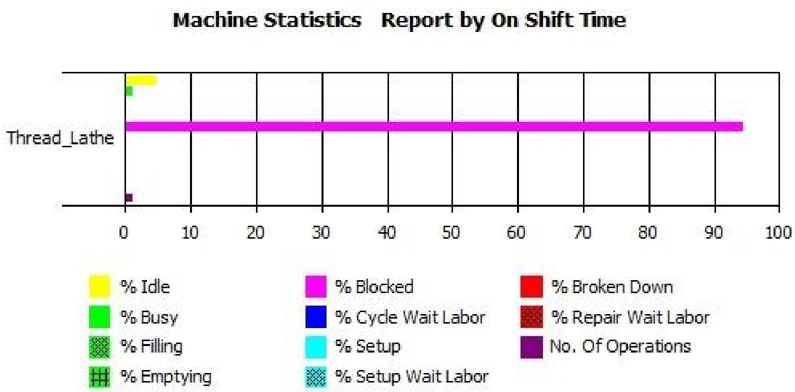
Machine statistics for Al_Ni_Composite_Washer



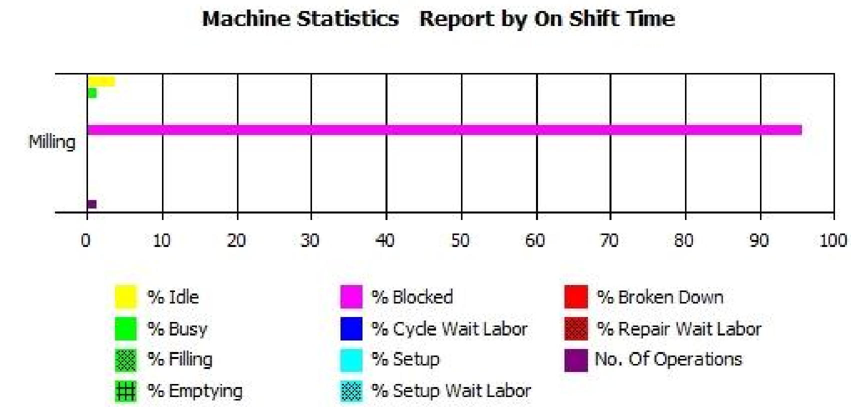
Al_Ni_Composite_Furnance



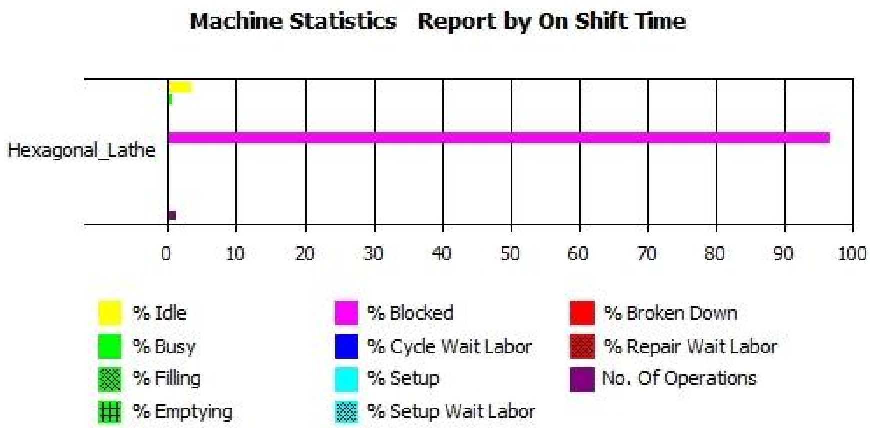
Machine statistics for Metal_Welded_Washer



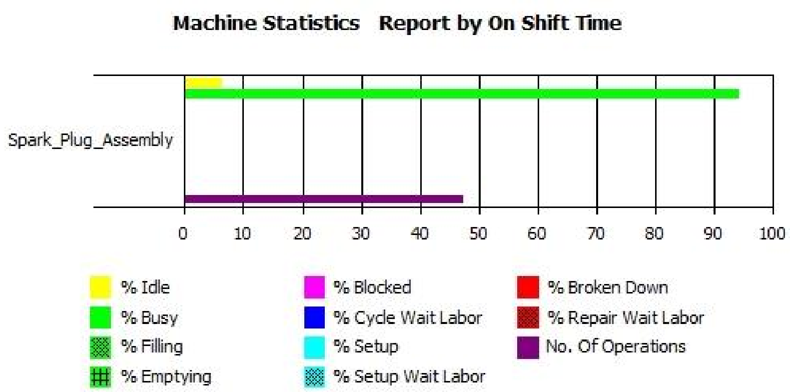
Machine statistics for Thread_Lathe



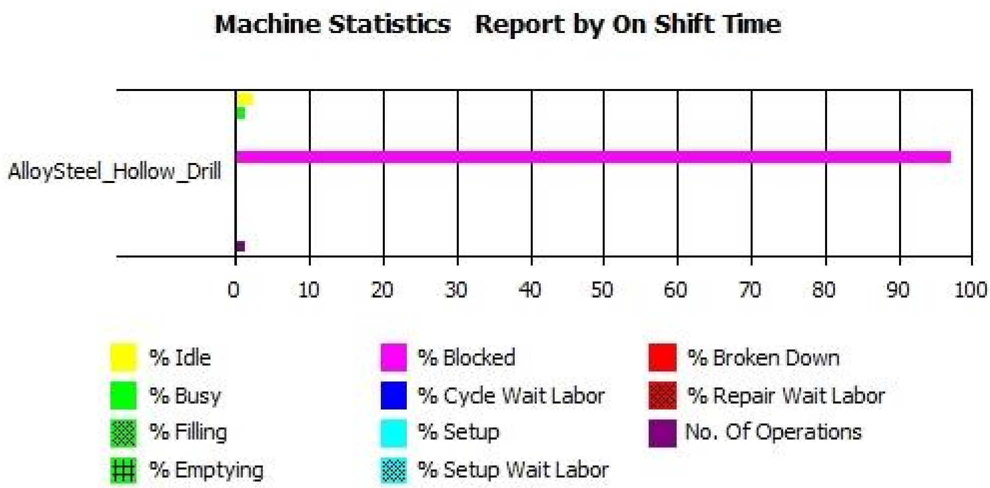
Machine statistics for Milling



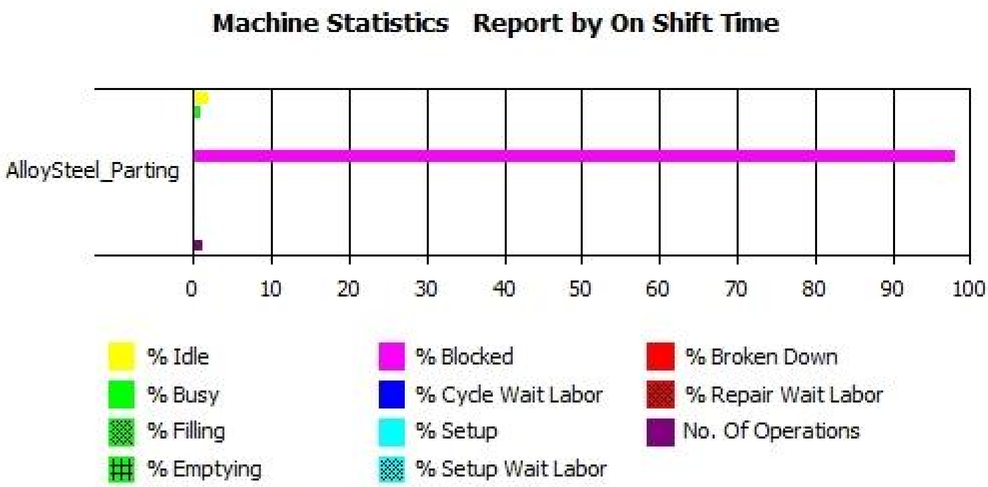
Machine statistics for Hexagonal_Lathe



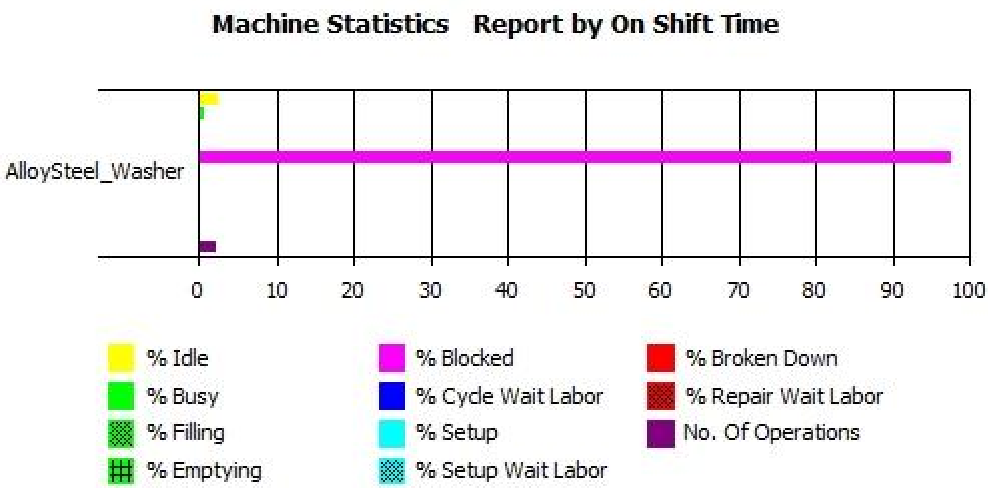
Machine statistics for Spark_Plug_Assembly



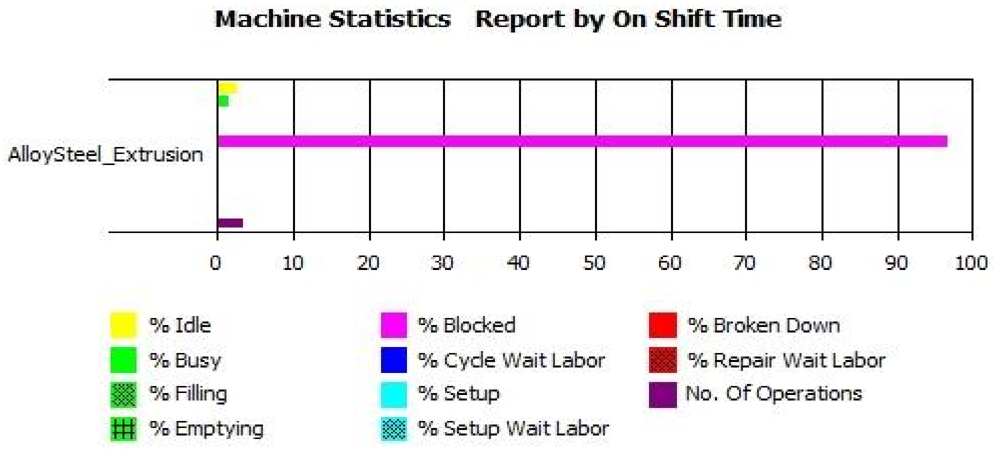
Machine statistics for AlloySteel_Hollow_Drill



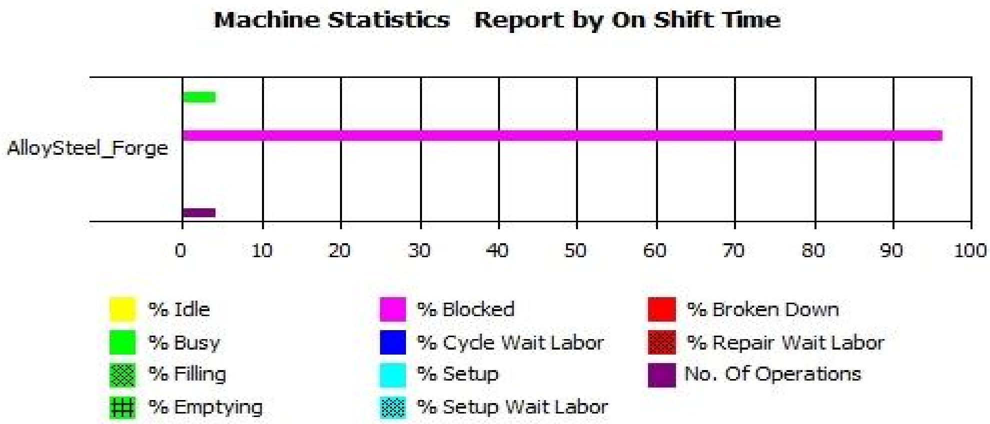
Machine statistics for AlloySteel_Parting



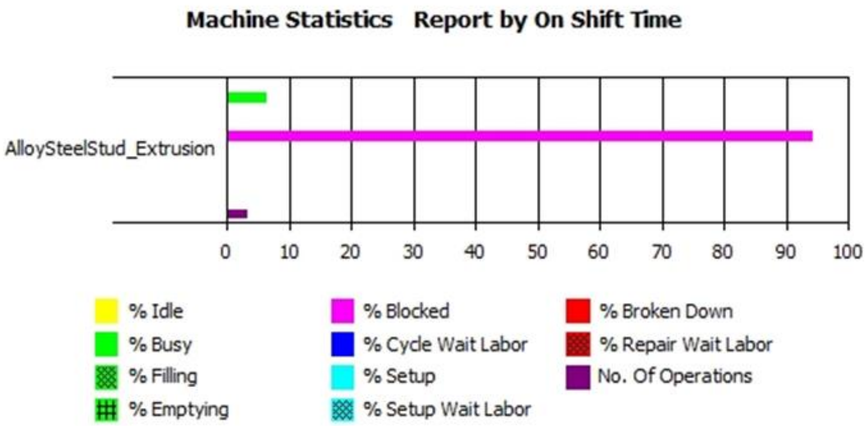
Machine statistics forAlloySteel_Washer



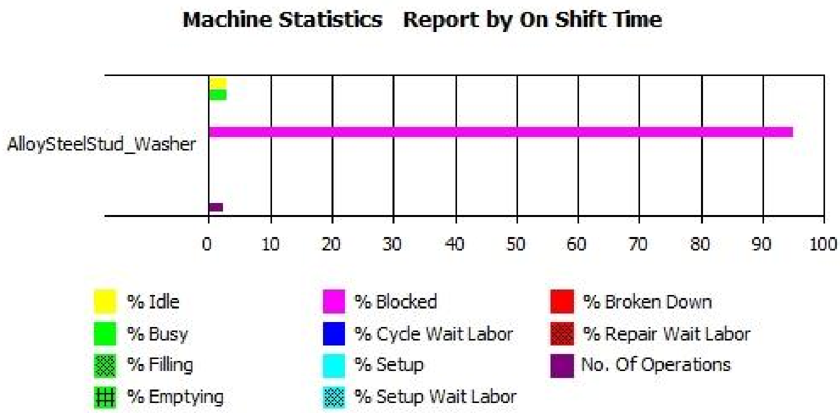
Machine statistics for AlloySteel_Extrusion



Machine statistics forAlloySteel_Forge

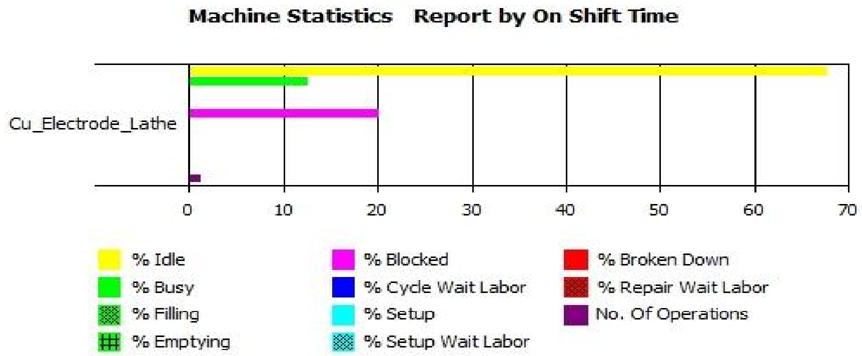


Machine statistics for AlloySteelStud_Extrusion

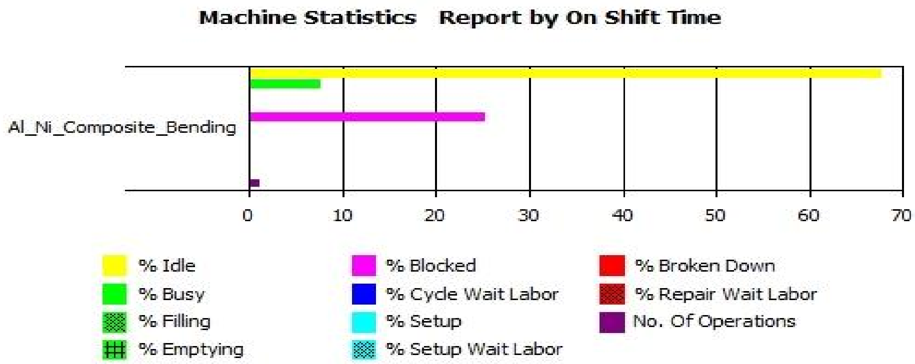


Machine statistics for AlloySteelStud_Washer

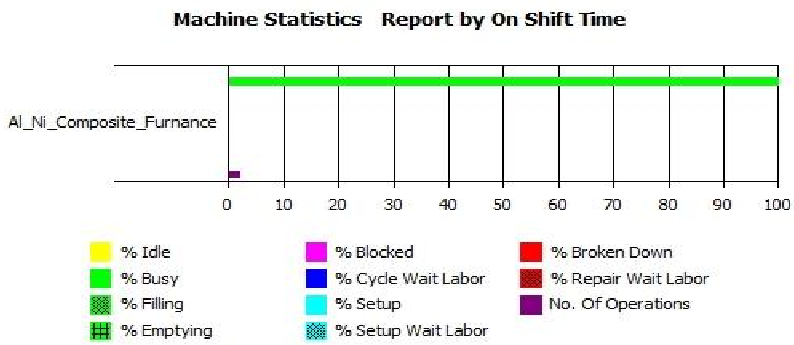
Appendix B: Machine statistics for 40 hours production run



Machine statistics forCu_Electrode_Lathe (40 hours)



Machine statistics for Al_ni_Composite_Bending (40 hours)



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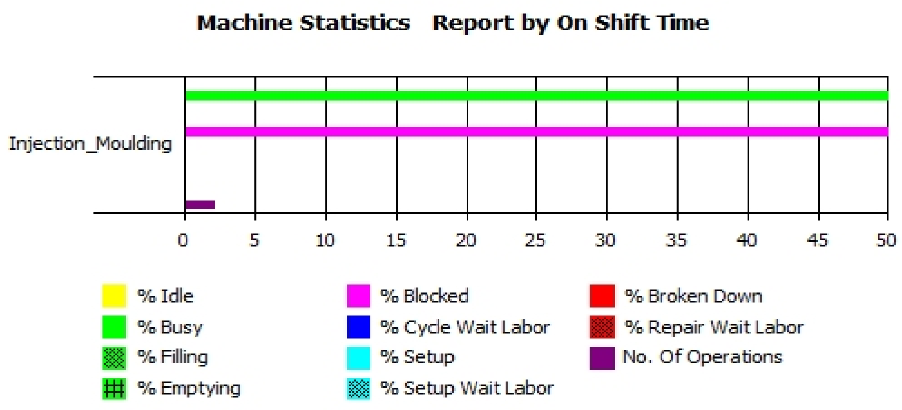
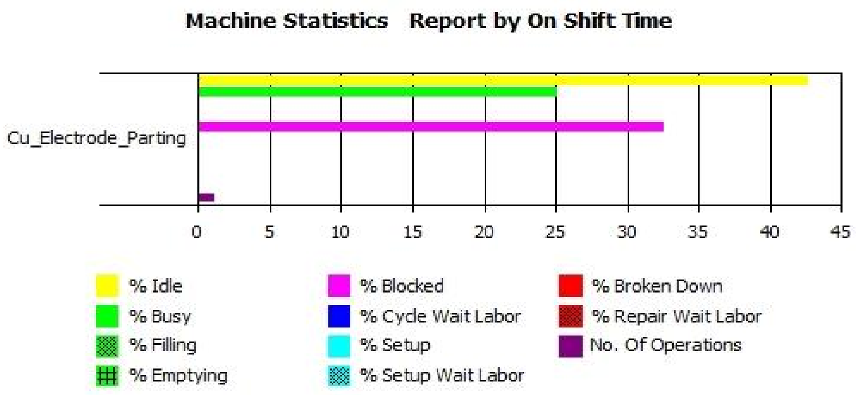
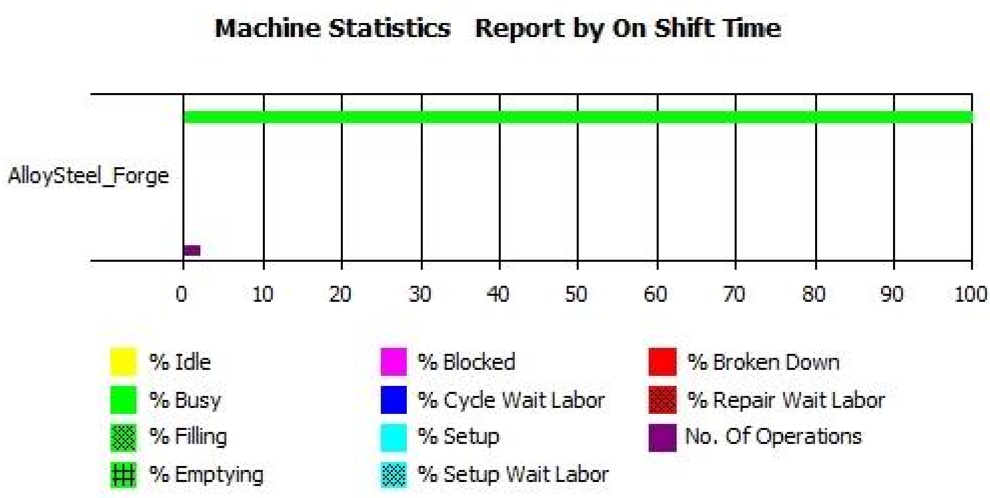
Machine statistics for Al_Ni_Composite_Furnance (40 hours)



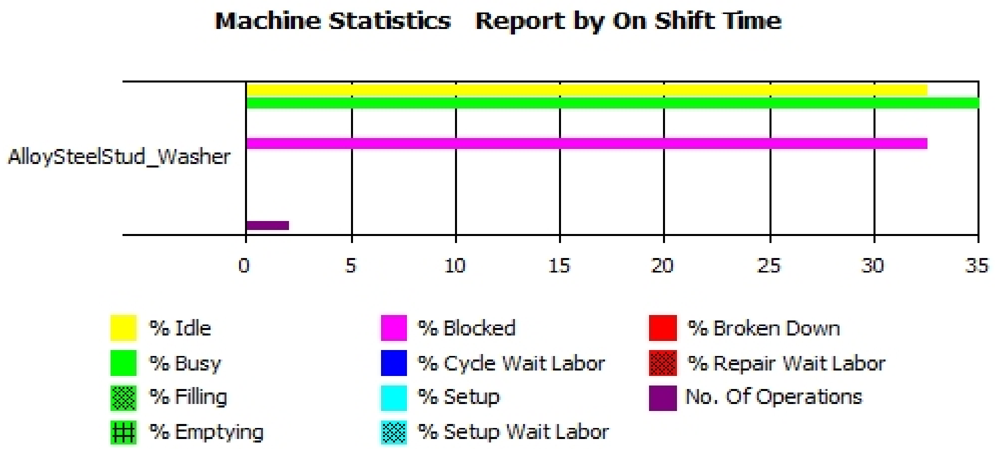
Machine statistics for Injection_Moulding (40 hours)



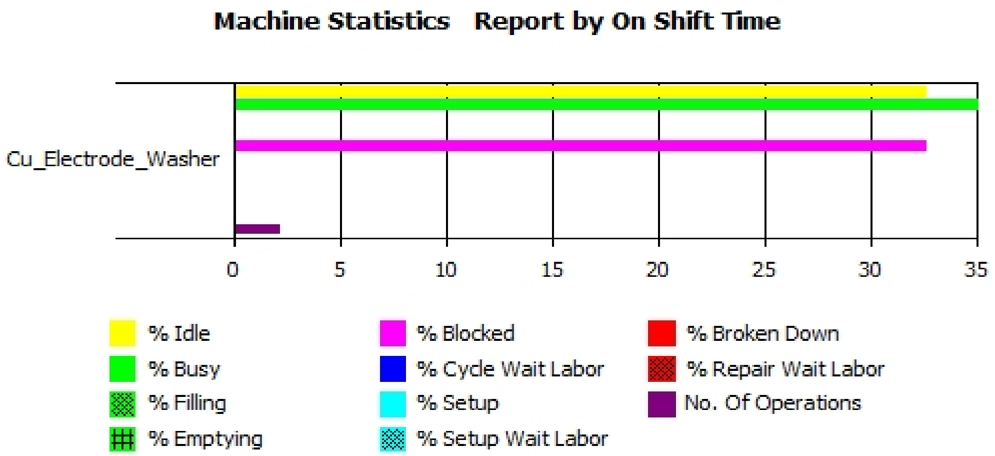
Machine statistics for Cu_Electrode_Parting (40 hours)



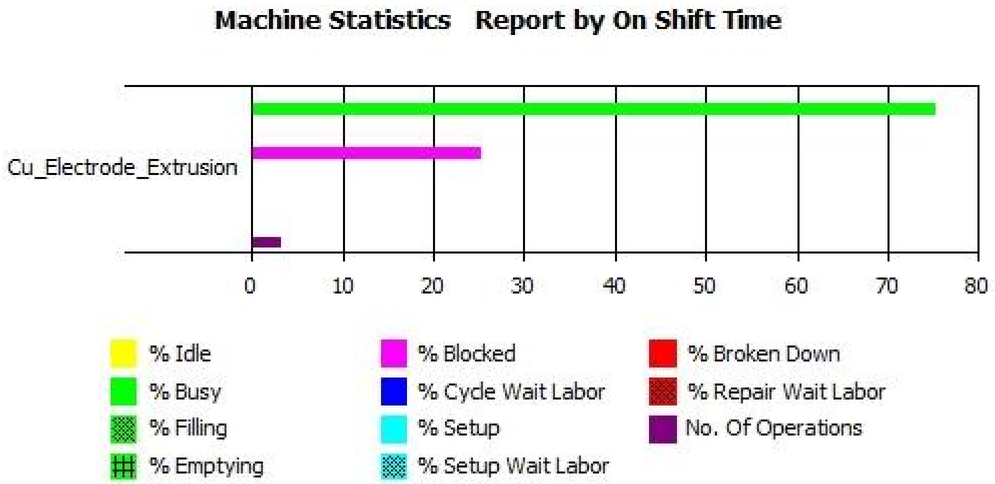
Machine statistics for AlloySteel_Forge (40 hours)



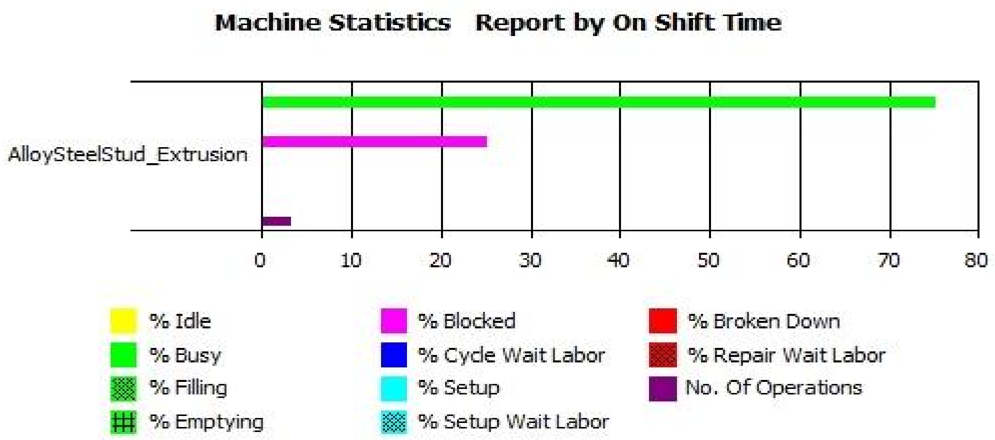
Machine statistics for AlloySteelStud_Washer (40 hours)



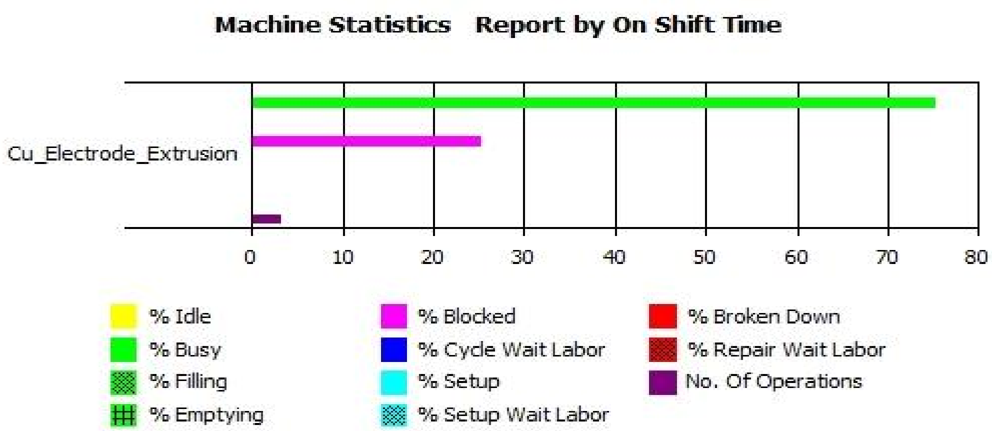
Machine statistics for Cu_Electrode_Washer (40 hours)



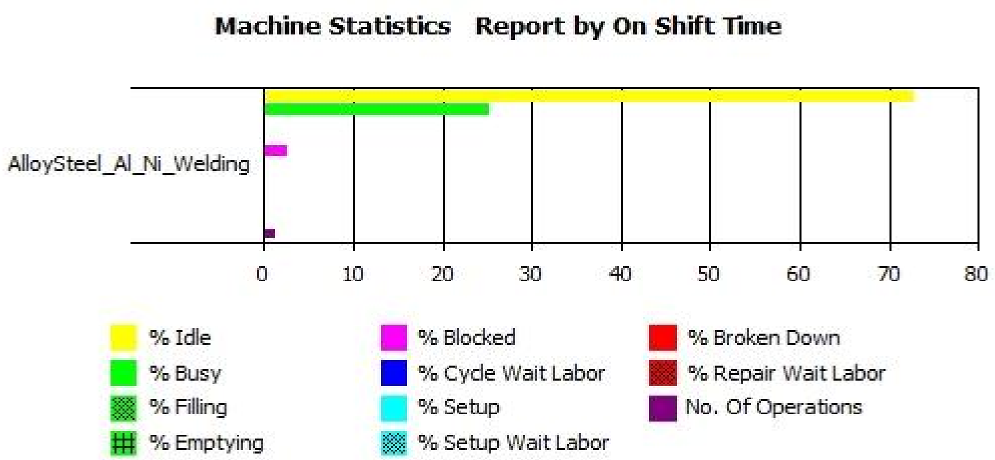
Machine statistics for Cu_Electrode_Extrusion (40 hours)



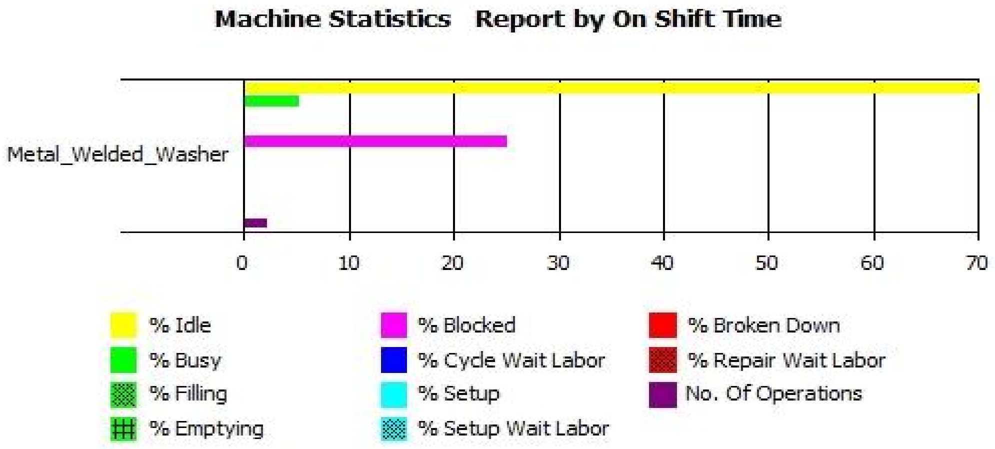
Machine statistics for AlloySteelStud_Extrusion (40 hours)



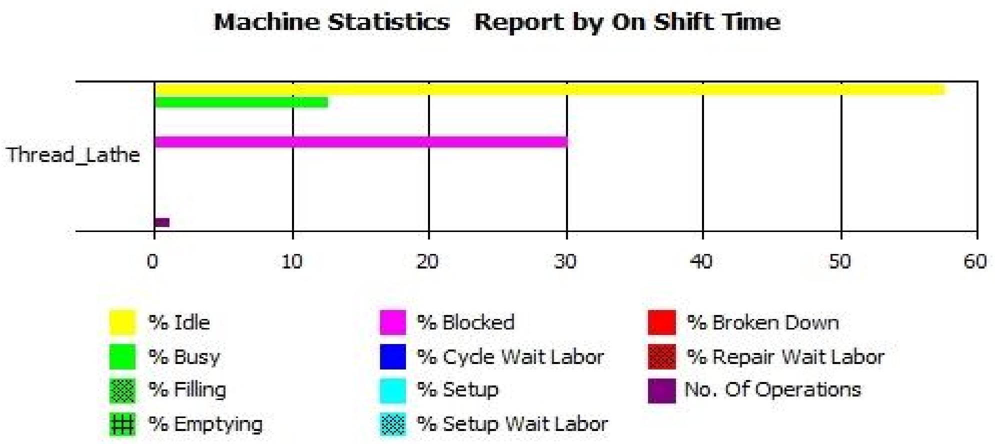
Machine statistics for Cu_Electrode_Extrusion (40 hours)



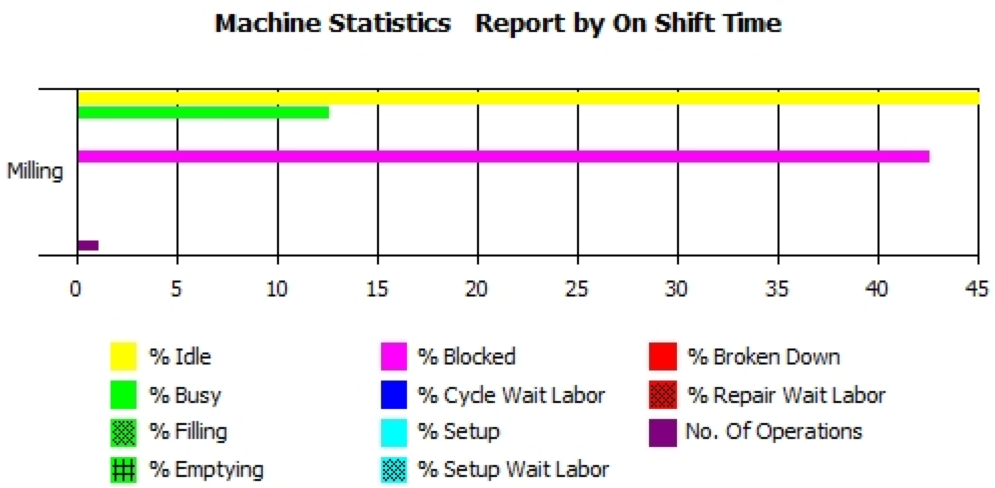
Machine statistics for AlloySteel_Al_Ni_Welding (40 hours)



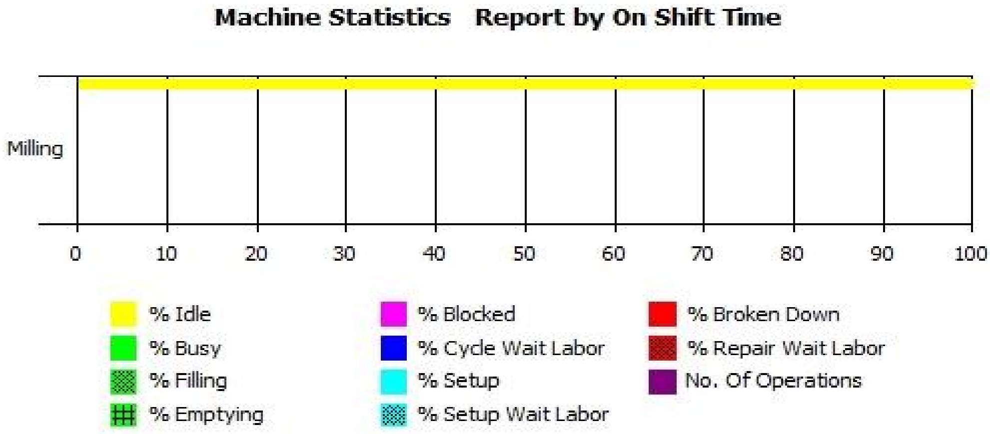
Machine statistics for Metal_Welded_Washer (40 hours)



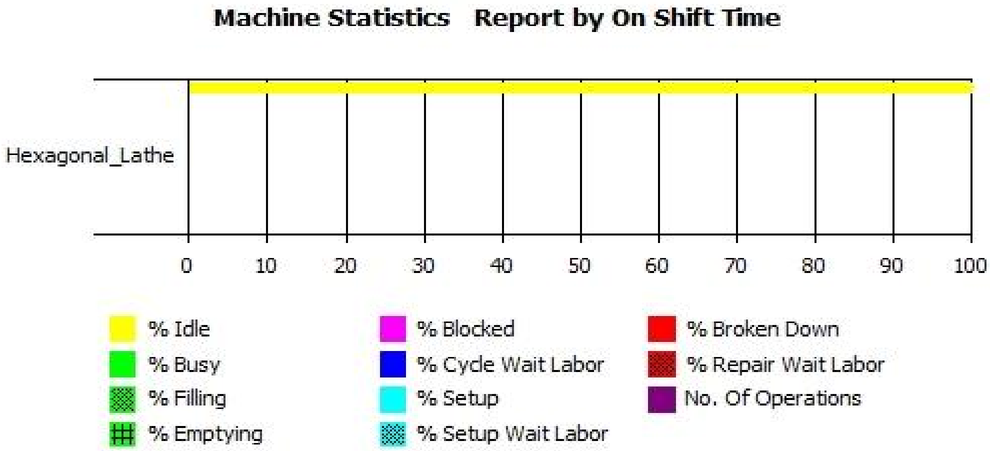
Machine statistics for Thread_Lathe (40 hours)



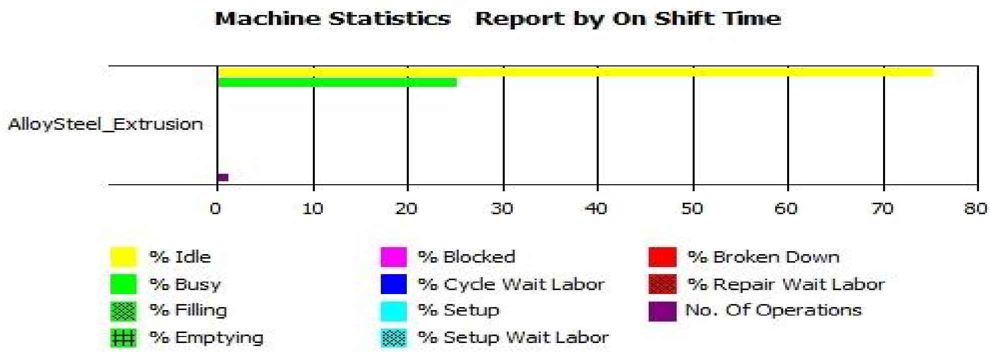
Machine statistics for Milling (40 hours)



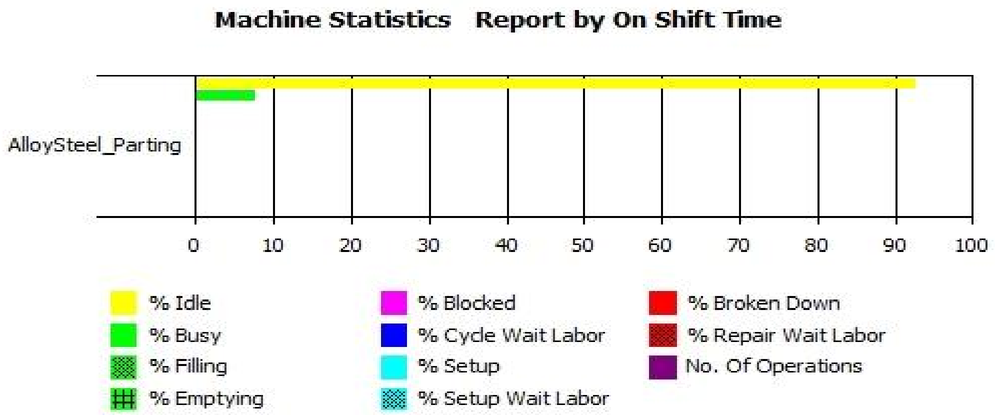
Machine statistics for Milling (40 hours)



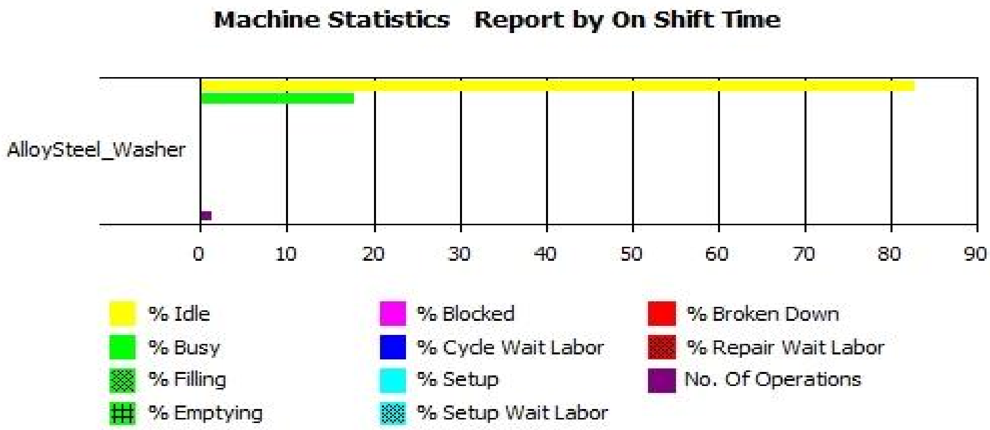
Machine statistics for Hexagonal_Lathe (40 hours)



Machine statistics for AlloySteel_Extrusion (40 hours)

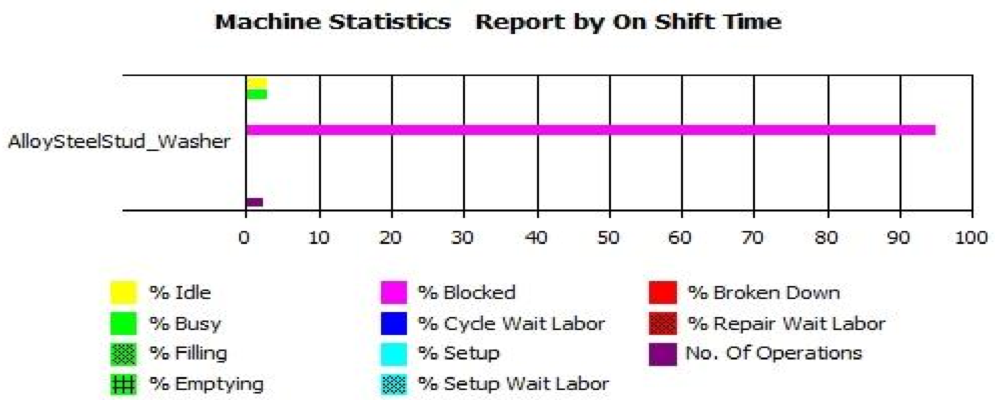


Machine statistics for AlloySteel_Parting (40 hours)

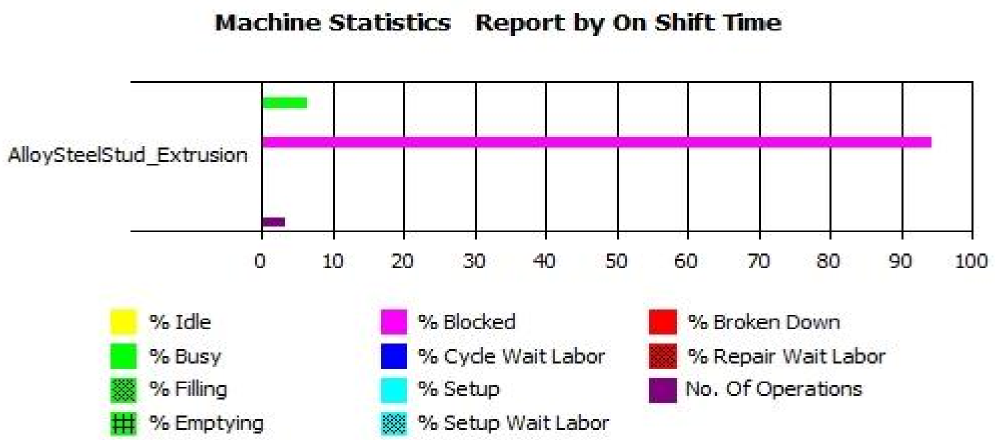


Machine statistics for AlloySteel_Washer (40 hours)

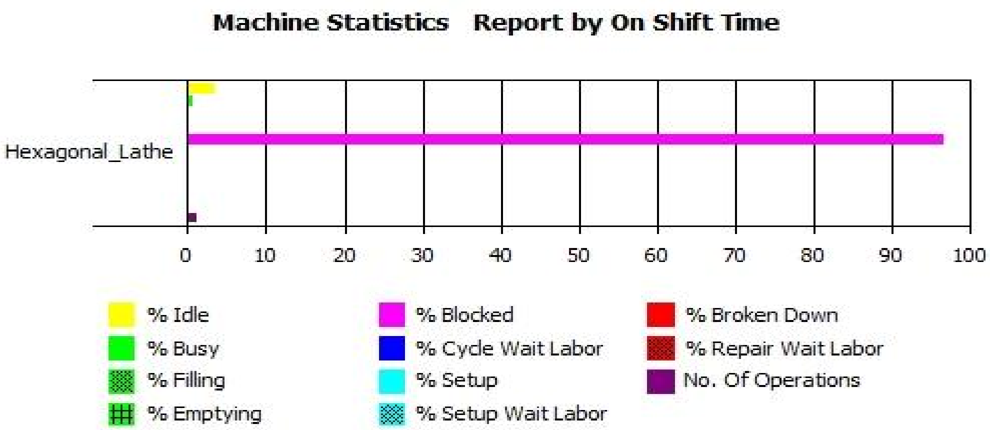
Appendix C: Machine statistics for 500 min production run



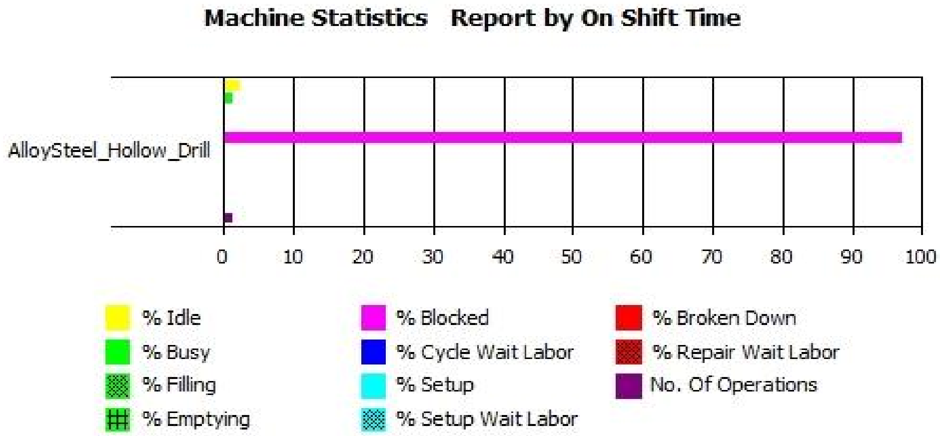
Machine statistics forAlloySteelStud_Washer (500 min)



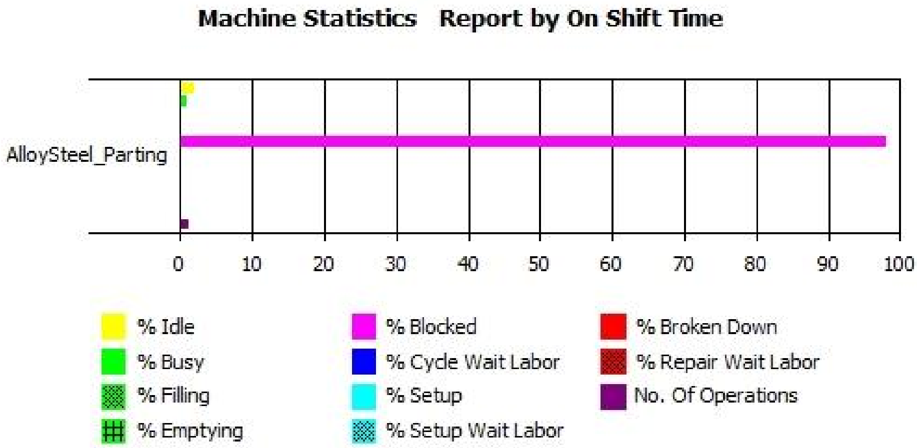
Machine statistics for AlloySteelStud_Extrusion (500 min)



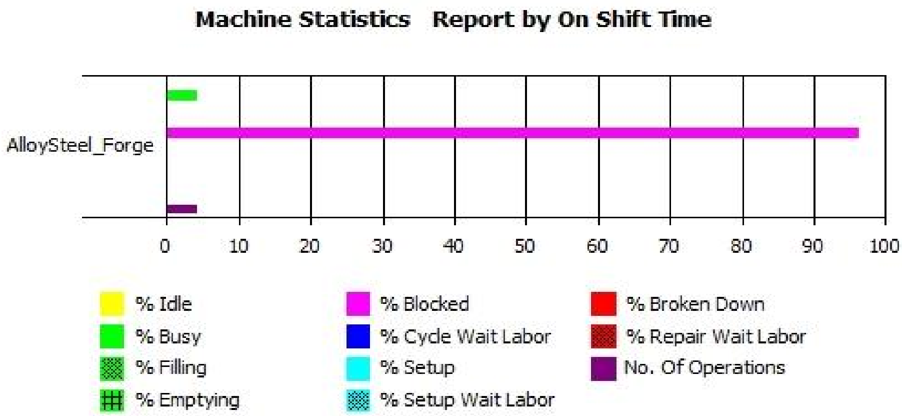
Machine statistics for Hexagonal_Lathe (500 min)



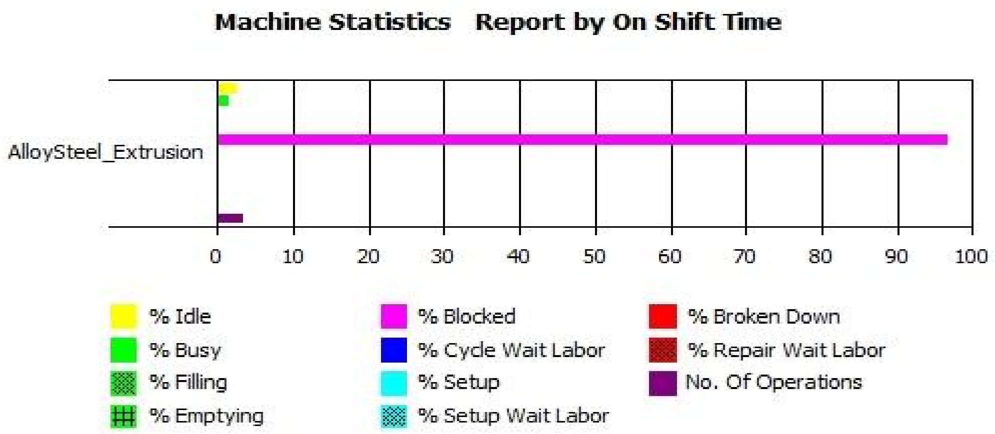
Machine statistics for AlloySteel_Hollow_Drill (500 min)



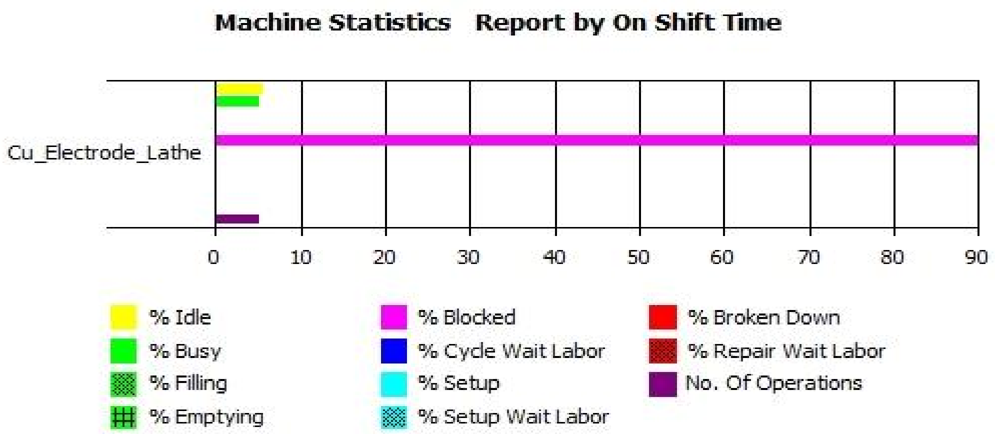
Machine statistics for AlloySteel_Parting (500 min)



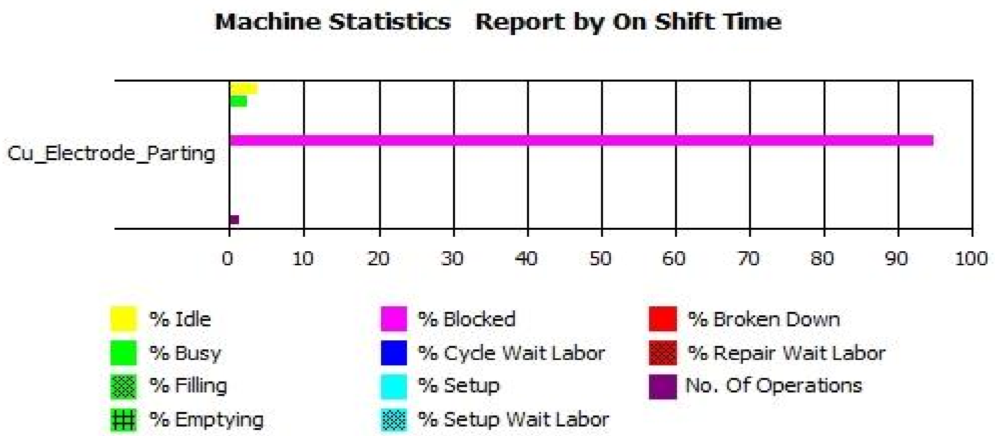
Machine statistics for AlloySteel_Forge (500 min)



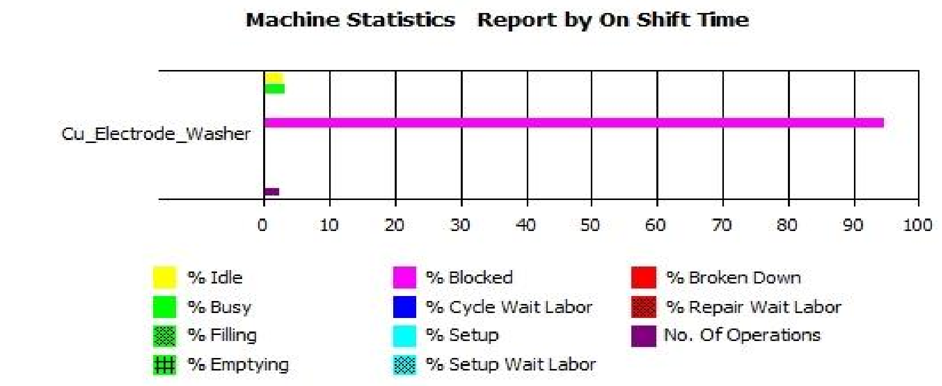
Machine statistics for AlloySteel_Extrusion (500 min)



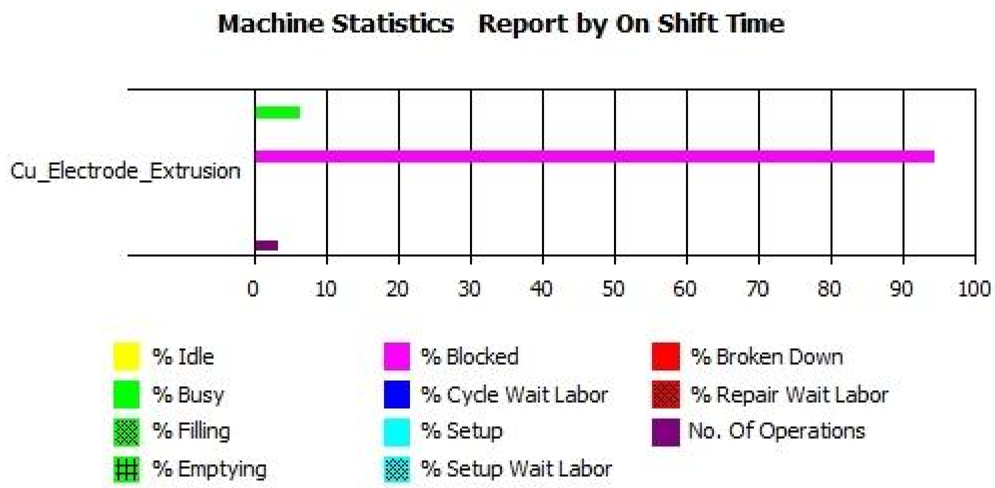
Machine statistics for Cu_Electrode_Lathe (500 min)



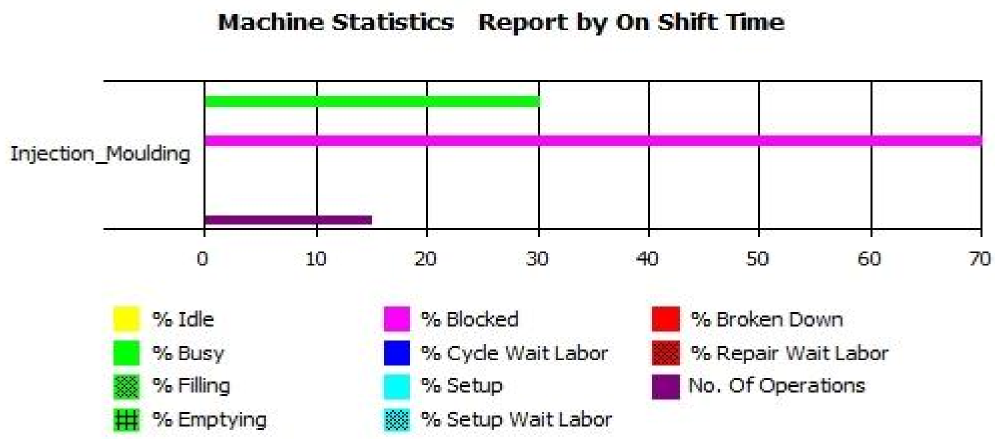
Machine statistics for Cu_Electrode_Parting (500 min)



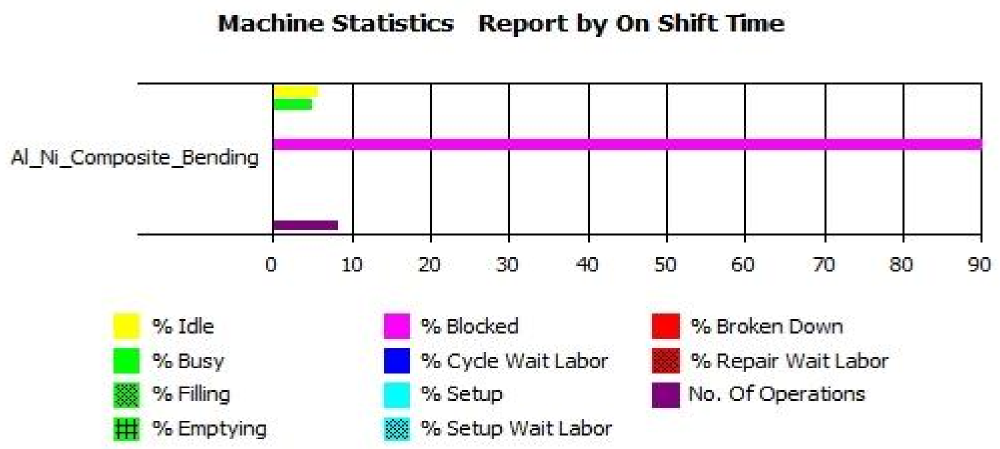
Machine statistics for Cu_Electrode_Washer (500 min)



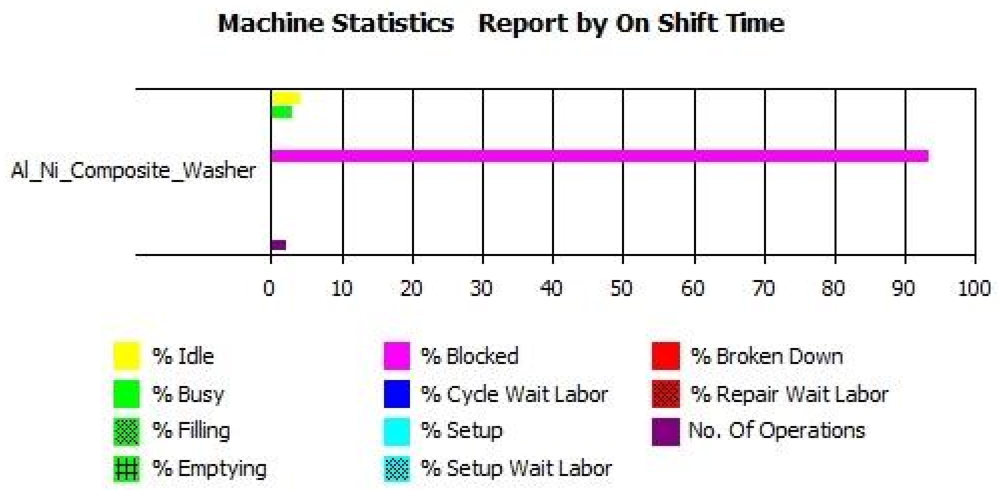
Machine statistics forCu_Electrode_Extrusion (500 min)



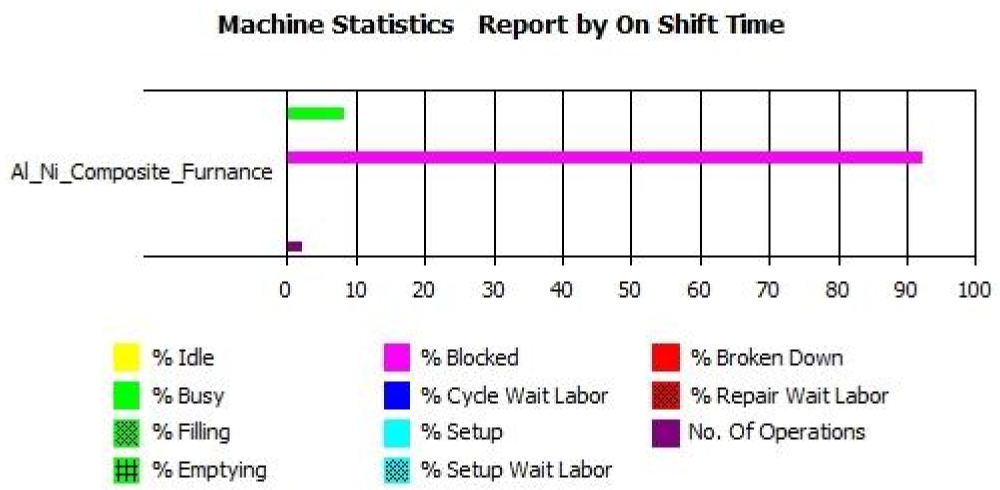
Machine statistics for Injection_Moulding (500 min)



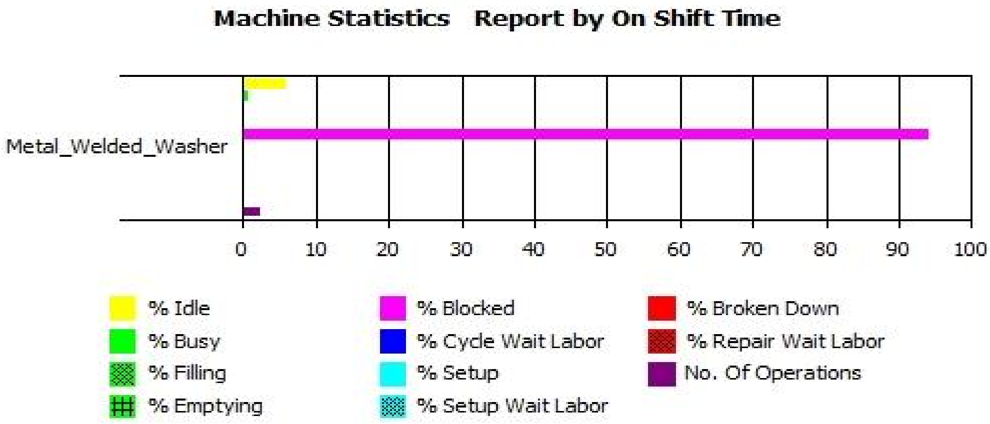
Machine statistics for Al_Ni_Composite_Bending (500 min)



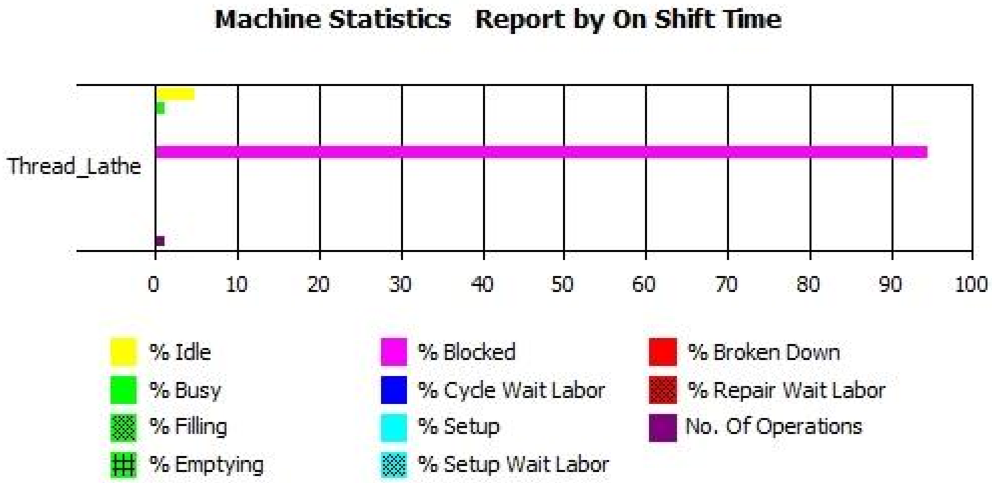
Machine statistics for Al_Ni_Composite_Washer (500 min



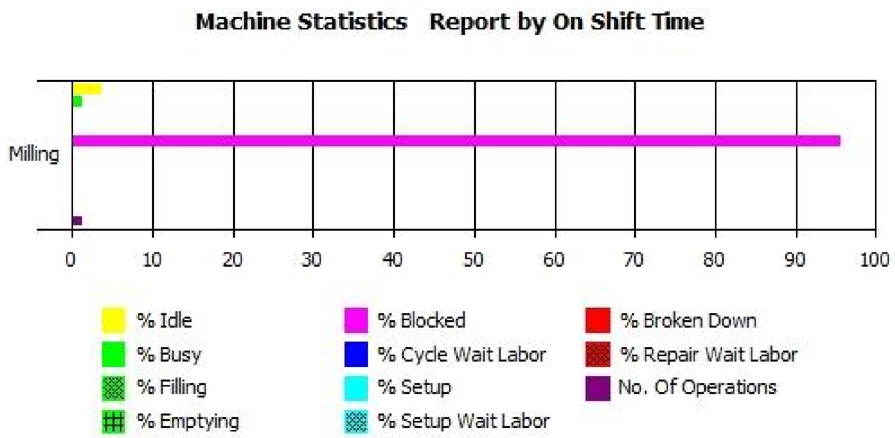
Machine statistics for Al_Ni_Composite_Furnance (500min)



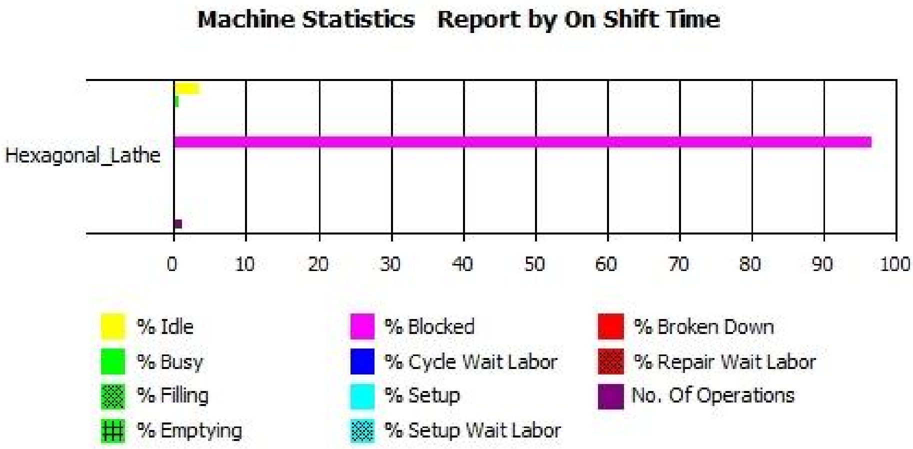
Machine statistics for Metal_Welded_Washer (500 min)



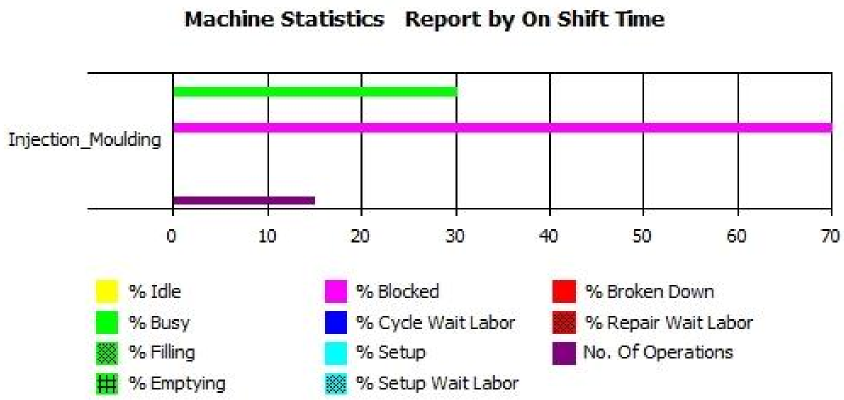
Machine statistics for Thread_Lathe (500 min)



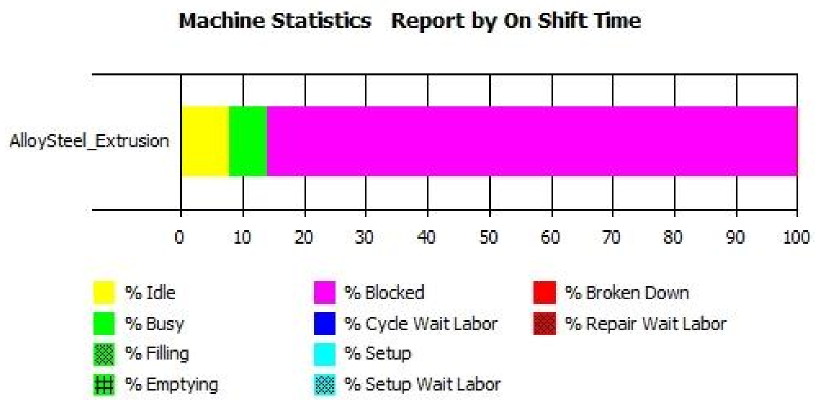
Machine statistics for Milling (500 min)



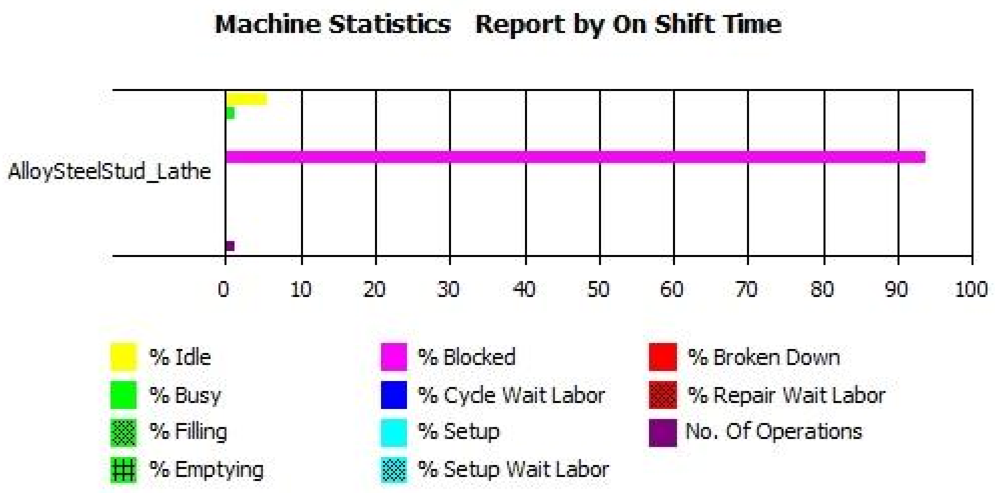
Machine statistics for Hexagonal_Lathe (500 min)



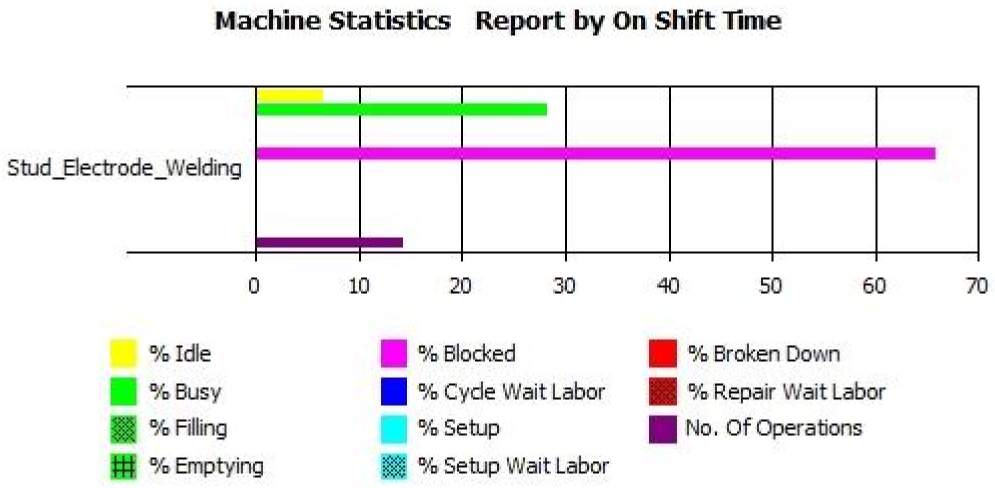
Machine statistics for Injection_Moulding (500 min)



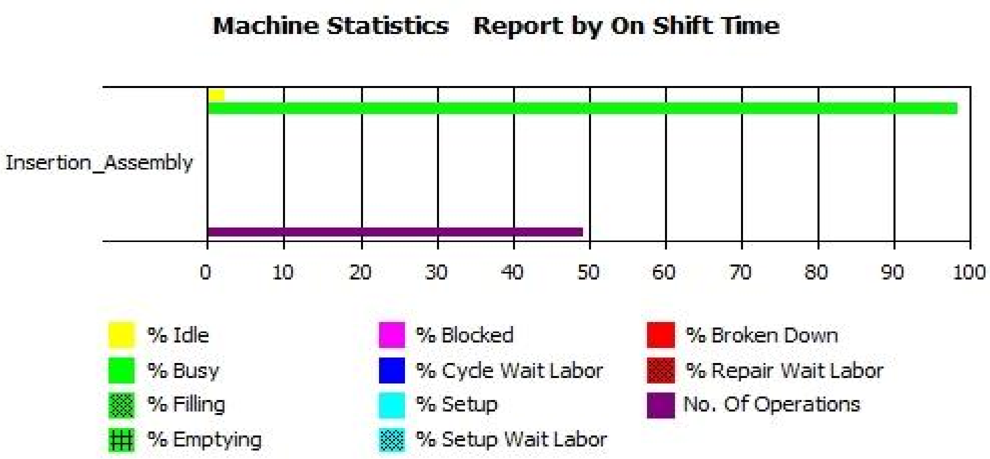
Machine statistics for AlloySteel_Extrusion (500 min)



Machine statistics for AlloySteelStud_Lathe (500 min)



Machine statistics for Stud_Electrode_Welding (500 min)



Machine statistics for Insertion_Assembly (500 min)

Appendix D: Data set for R-Studio

Name of company	No of workers = >100	Turnover (£ M)	Production rate/ day	Machining flexibility (%)	Operation agility (%)	Machine idle time (%)	Breakdown time (%)	Machine set up time (min/hr)	Annual inventory cost (£1000s)	on time delivery (yes -1 or no- 0)	Reject rate (%)	Resource utilization (%)	Total production lead time (in days)
BCS	Yes	12.5	2000	60	25	20	26	5	200	1	20.5	45	20
AKN	No	2	200	50	40	32	18	4	190	1	30	40.4	10
KKC	Yes	5	500	65	30.3	30.4	30	6	180	1	20.4	65.5	10
CMN	Yes	4	200	65	19	25	28	6	80	1	25.5	62.3	15
RUS	Yes	1	50	50	12	42.3	22.2	20	50	0	12.3	50.3	10
PEN	No	2	5	35	18	20.4	26	5	170	1	20.3	49.2	5
ABC	No	2.5	1000	87	30	30.2	30	6	100	1	19.2	62.7	20
3M	Yes	6	25	65	26	25.7	28	6	160	1	22.7	73.7	10
JBL	No	1.5	20	30	15	33	38.3	10	50	1	33.7	40.1	10
BVD	Yes	3	30	45	10	40	26	5	150	1	40.1	32.3	10
DHL	Yes	6	50	65	38	12.3	30	6	70	1	22.3	45.5	15
IEA	No	3	500	75	38	45	29.9	6	65	1	45.5	59	15
CVS	Yes	5.5	25	64	23	39	44.2	22	120	1	29	68.5	10

BL	Yes	1.3	200	65	24	38.5	39	20	110	0	38.5	37.3	5
SEO	Yes	4	30	64	27.4	37	37.5	13.5	90	1	37.3	47	15
DA	Yes	3.4	25	49	19	37	30.3	20.5	85	1	37	40.2	15
PR	Yes	2	100	81	11	40.2	37	5	111	0	40.2	53.5	20
AM	Yes	9	150	77	10	43.3	40.1	4	190	1	43.5	54.2	5
37s	Yes	7.5	200	57	17	42.2	40.3	10	89	1	32.2	49.9	20
A&B	Yes	107	250	55	29	19.9	42.2	2	95	0	9.9	41	10
37C	Yes	20	3000	67	23	22	19.1	3	205	1	21	63	10
ABC	Yes	10	1200	72	28	32	23	6	69	0	33	54	15
27B	No	2.7	750	87	23	24	34	1.5	55	1	24	49.2	10
AWRBE	Yes	4.2	125	46	39	39.2	24	13	120	1	39.2	38.5	5
ABLOY	Yes	9	25	77	38	38	39.2	16	105	1	38.5	50.5	20
12e	Yes	7.8	30	56	37	20.5	38.2	30	192	0	20.5	48	10
ABN	No	1.2	100	65	28	28.4	26	5.5	172	1	28.4	62	10
AMR	Yes	2.6	25	69	19	23	29.1	2	79	0	2.8	60	10
AMRO	No	9	20	72	30.2	5	23.3	4	95	1	5	3	15
ACER	No	0.2	20	74	37.3	32	5	3.4	100	1	32	39	15
AJME	Yes	1.9	50	69	10	37	32	2	182	1	37.1	48	10
XXE	Yes	2	25	62	29	18.9	37	9	110	1	18.5	55	5
ALZA	Yes	6	100	58	21	30.2	18.9	7.5	104	0	30.2	65	15

AMBEV	Yes	0.75	20	90	30	43	30.2	10	120	0	43	59	15
AFFA	Yes	11	25	74	26	20	43	10	173	1	24.3	4	20
19E	Yes	10.3	60	73	32	22	20	18	100	0	49.2	55	5
AMC	Yes	3.8	30	77	9.9	31.5	22.3	20	140	1	10.4	49.3	15
ACTS	No	0.75	100	75	12	31	18.4	15	110	1	29.2	60	20
ATT	Yes	12.5	90	68	18	29	30.5	5	80	0	20.9	54	10
ASUC	No	5	80	82	14	29.9	21.4	7	55	0	32.7	68	10
ASCS	Yes	17	30	80	29	40	29.4	20	180	1	40.1	65.4	15
BQ	Yes	11.2	20	90	22	39.5	23	1.9	100	0	22.3	67	10
BAPE	Yes	13	1200	77	21	38.1	28	8	130	0	44.5	65	5
BALLY	No	5	200	78	28.4	29	23	4	50	0	29	47.5	20
BHPV	Yes	7	600	67	38	0.9	39.5	16	150	1	37.5	54	10
BANGQ	Yes	22	300	65	33	50.1	38	10	170	1	37.3	44.3	10
HM	Yes	1.9	450	70	18	45.2	37	7	65	1	36.6	67.7	10
HRB	Yes	8.8	20	71	19	35.5	28	20	120	1	40.2	65	15
HAAGE	No	4	270	40	20	17	19.5	1.4	120	0	43.5	40	15
GGG	Yes	16	120	29	21	19	30.2	20	90	1	32.2	70	10
BB	No	10	150	87	20	20	37.3	22	87	0	989	60.5	5
BC	Yes	7.2	20	37	16	32	10	4	111	1	21	29.5	15

HALR	Yes	2.5	30	61	13	32.4	29	6	191	0	332.3	38	15
DBOS	No	1.4	30	29	28	40	30.3	10	89	1	24	43.6	20
GECC	Yes	19.6	200	91	39	28.1	37.2	12	95	1	39.2	59.6	5
MAGG	Yes	22	120	77	41	18.5	20.3	17	133	1	35	50	20
MAN	No	4	10	39	16	32	19.9	13	69	1	20.5	71	10
MNDVA	Yes	5.6	25	56	29	30	29.1	14	155	1	28.4	38.7	10
LOT	Yes	9.3	50	70	26	26.8	38.5	20	120	0	2.8	57	15
LUK	Yes	12	100	59	32	34.2	37	12	115	1	6	55	10
LVMH	Yes	17	150	56	37	33	37	18	182	1	19	60	5
PACCW	No	28	25	49	38	40.2	40.2	20	112	1	30	50.9	20
PEZ	Yes	37	10	81	39	25.7	43.3	15	77	1	30.2	45	10
BENQ	Yes	20	10	72	32.7	34	42.2	5	95	1	40.2	59	10
UPN	Yes	26	20	83	28.3	1	19.9	7	100	1	43	39.8	10
NSSP	No	7	50	51	23	23	22	20	138	0	32.4	56	15
TEPCO	Yes	18.6	40	59	26	9	32	1.9	112	0	20	64	15
TN	Yes	42	100	66	22	48	24	8	104	1	30.1	61	10
UBS	Yes	30	200	69	27	44.2	29.2	14	127	0	22.1	33.6	5
THY	No	7.9	150	77	29	35.3	28.7	16	145	1	45.5	60	15

PPC	Yes	23	25	74	11	41	22	12	57	0	29	50.5	15
TXN	Yes	42	30	64	17	28.2	26.9	17	130	0	43.2	55.3	20
DTKK	No	23	100	90	14	39.4	32.2	20	150	0	30.2	61	5
TVE	Yes	14.9	150	38	16	38.3	35.3	1.5	65	1	37	45.5	5
RSMC	No	33	200	20	22	35.1	12.8	20	120	0	40.2	50.1	20
TATT	No	3.9	320	88	26	18	21	22	110	0	43.5	53	10
MMM	Yes	38	60	77	24	16.7	32.3	1	95	0	28.2	55	10
UCLA	Yes	11	80	65	22	28	32.4	19	89	0	9.9	49.2	15
ZC	Yes	1.2	20	77	37	29.3	40.5	10	114	1	22.9	46	10
K1	Yes	8.1	15	20	35	30.3	29.1	12	190	1	34	50.5	5
KZPSS	Yes	9.4	75	87	33	32	18.5	18	89	0	24	47	20
YK	No	8	130	65	10	17.7	33	30	105	0	19.9	54.5	10
PPI	Yes	2	15	64	9	20.7	30	22	123	1	38.5	56.7	10
AAA	Yes	35	80	73	13	32.9	26.8	17	69	0	21.5	30.45	10
PHLCO	Yes	27	20	72	25	37.2	34.2	18	125	1	28.4	47	15
OCC	Yes	18	30	69	22	11	35	22	120	0	4.6	44	15
NOVL	Yes	29	30	79	21	19	40.6	15	116	1	7.5	58.6	10
PCCW	No	10	25	72	23	15	25.7	15	180	1	32	60	5
NVDIA	No	20.8	100	57	24	37	36	7	110	1	27.7	59.5	15

PEZ SHA	No	15.9	15	68	48	33	16.4	21	75	0	18.5	50.3	15
SM EXS	Yes	14	20	55	52	25.9	23.5	1.9	95	0	20.2	54.5	20
SCO	Yes	2	25	60	38	36.2	19.9	18	101	0	43	49.3	5
SAS OL	Yes	8.3	50	72	10	17	48	14	129	1	24.3	40	10
VAL RA	Yes	0.3	75	88	17	22	44.6	15	102	0	39.7	55	15
VDF	Yes	8.1	15	80	38	27	37.3	12	105	1	11.5	65	10
VLO LG	No	0.9	25	81	36	19	17	27	69	0	29.2	65.4	5
TW N	Yes	1.4	100	57	39	23	19.9	10	127	0	28.9	67	20
S1	Yes	2.8	200	67	27	16	10.7	5	60	0	32.7	65	10
TWI TT	Yes	19	25	72	11	43.8	9.9	10	130	1	40.1	47	10
SM S	Yes	20.7	60	52	52	43	18	22	140	1	23.3	54	10
ZYN GA	Yes	22	200	59	49	34.9	18.3	7	65	0	44.5	44	15
YAP P	No	9	500	68	53	33	12	19	110	0	29	66	15
ZUS EE	Yes	3	50	61	60	36	17.7	11	110	1	35.5	48	10
YAH AM	Yes	7	125	60	61	30	19.9	12	195	1	36.6	36	5
MN C	Yes	3.2	175	72	55.3	22	27.9	10	89	0	12.5	69	15
SDD	No	2.3	49	44	37.4	32	45.2	5	114	0	30.2	62	15
TN NV	No	3.6	67	80	43	28	34.4	20	120	0	43	27	20
TK100	Yes	9.2	66	77	11	30.4	38.9	22	79	1	38	30	5

VOCAP	Yes	1.7	76	67	17	30.1	41.2	15	105	0	44.5	44	20
VC	Yes	3.1	77	82	27	19.2	23.2	10	123	0	10.4	57.5	10
EEE	Yes	9	80	90	18	23.3	29.3	20	99	0	32.5	55.4	10
VIRNE	No	7.9	82	55	19	30.3	28.8	10	125	0	20.9	60	15
SMRTI	Yes	6.6	87	76	23	22	27.7	15	120	0	30.5	40.6	10
AITEL	Yes	3.4	72	82	38	17.8	29.8	7	139	1	40.1	29	5
SSK22	Yes	7	70	57	36	29	22.3	12	180	0	22.3	44	20
ZIMME	No	3.5	66	65	38.4	22.2	30.4	13	119	1	40.4	66	10
SPRYIP	Yes	2.5	71	66.3	39	23.8	52.1	12	75	1	29	48.7	10
KKO	Yes	5.9	72	80	38	35.4	25.8	9	95	1	36.3	54	10
KMART	Yes	13.2	55	80.1	40.1	44	52	15	101	0	24.7	44.3	15
KIMAT	Yes	8.2	62	55.9	28	38	33	10	129	0	36.6	55.8	15
KENWT	No	4.2	53	39.8	33.1	27	25.5	25	182	0	40.2	65	10
LADA	Yes	21	67	40.8	11.4	45	21.3	10	105	1	33.4	69	15
SWTS	No	2.2	78	67	22.4	21	23.7	5	209	0	32.2	51.3	10
STLLEN	Yes	31	70	72.3	44.1	24	40.1	10	100	1	54	60	5
LEGE10	Yes	12	25	65	23.4	49	38.7	7	101	0	33.2	29.5	20
LEXMK	Yes	76	64	76.2	9.9	28.9	33.5	7	125	0	332.3	38	10

KONC	No	27	125	55.9	10.2	23	37.9	19	102	0	24	44	10
DAFT	Yes	11.3	20	60	18.9	16	20.3	12	105	1	36.3	57	10
DSF	Yes	14	55	78	16.5	16.9	18.9	9	99	1	35	39	15
CVS	Yes	16	60	80.3	12	10	27.8	5	127	0	23.1	70	15
CPLF	No	7	220	60.3	17	9.9	33.4	2	160	0	28.4	38.7	10
DIXNS	Yes	15	10	72.4	24	18	40.5	10	130	1	30.4	49	5
NDLN	Yes	12	25	90	37.1	18.3	25.1	23	150	1	36	58	15
DFP	Yes	18	50	91.1	43	12	27.2	15	65	0	19.9	65	15
DD25	No	19	20	70	29.4	17.7	19.4	10.5	110	0	30	50.9	20
ZZZ	Yes	20	440	45.6	32	19.9	17.8	20	110	0	30.2	42	5
Y2Y	Yes	22	80	65.5	21	27.9	35.5	10	195	1	40	59	20
APP50	No	19	140	72	55	47	50.1	15.5	189	0	26	40	10
A100	No	2	22	54.6	46	34.4	22.8	7	114	0	25.4	56	10
ARCOR	No	5.1	130	78.5	39	38.9	54.5	10.5	120	0	36.2	63	15
AIZXA	Yes	26	30	80.2	29	41.1	43	13	89	1	17	62	10
SMK	Yes	19.5	25	45.9	8	33.2	22.4	12	105	1	23	33.6	5
C34985	Yes	13.8	75	60	9.2	29	21.4	9.5	153	1	30	55	20
PEJRPJE	Yes	18.1	230	48.8	50.1	28.8	33.7	3	99	1	40	50.5	10

AKLF	No	9	140	80.7	55.6	27.7	41.1	10	155	1	33.3	67.4	10
GPRJT	Yes	7.2	15	67.7	39.1	38.1	37.7	25	120	1	29.5	61	10
ROTE98	Yes	8.8	80	0	44.4	11	33.7	10	129	1	45.5	44.5	15
87JH	Yes	15.2	20	54.9	20	18	37.9	5	180	1	50	69	15
RPUTG	Yes	22.1	65	44.8	21	22	20.4	10	159	1	29	54	10
CNHLK	Yes	22.7	90	72.4	27	28	18.9	7	195	1	12.9	37.7	15
DFHI	No	9.1	70	60.5	30.4	32	26.9	7	95	0	10.5	56.7	10
RPUTG	Yes	10	15	60.1	60.2	9	32.7	19	201	1	17.8	30	5
909TSH	Yes	20	20	50.6	30.3	17	40	12	129	1	26.6	43	20
QPOI	Yes	29	30	57.9	43.3	56	25.1	10	180	1	39	44	10
EMTN	Yes	12.9	100	55	40.1	36	29	6	103	1	22.5	58	10
LJLI	Yes	8.2	90	45.2	58.3	22.3	29.4	4	200	1	33.9	60.5	10
JKL	No	9.5	12	90.3	56	33.4	32.9	10.5	80	0	29	59.5	15
UTY00	Yes	2.2	25	60.3	59	32.7	40.7	19	100	1	240.6	54.4	15
TOIUOT	Yes	4.7	30	76.1	45	40.1	37.7	10	96	1	34.2	54.5	10
HWEOI	Yes	8.1	100	82.1	48	39	33.2	15.5	109	0	33	45	5
IUTU	Yes	5.6	300	53.8	58	25.7	37.9	7	127	1	20	5	15
EITUP	No	7.7	200	65.1	51	57	19.7	6.5	101	0	17	55	15

GHOER	Yes	9.7	250	76.2	55.3	50.2	21.9	10.3	130	0	29	65	20
OYQER	Yes	4.7	25	49.2	33.9	23	39.4	12	140	1	23	4	5
SHYY	Yes	20.1	30	75.1	44.7	32	16.9	10.5	95	1	24	66	20
23M90	Yes	20	50	90.1	70	14	30	3	110	0	35.4	44	10
DRDE	No	9.9	110	64.6	10	20	30.5	10	101	0	44.6	59	10
DAHP	Yes	3	105	66.7	12.8	58	31.6	25.5	130	1	37.1	58.8	15
DELK	Yes	7	600	72.1	22	44.1	17.9	10	260	1	20.8	44	10
FCKU	Yes	6	100	83.2	25	39.1	11.6	5	180	1	35.7	65.5	5
DHOIW	Yes	7.7	70	92.1	30.2	20.3	20.9	10.5	150	1	32	39.5	20
FINIR	No	1	25	90.1	33	22	39	7	89	1	37.9	45.3	10
AHFKD	Yes	0.9	30	30.8	45	1	11.5	7.5	125	0	20	69	10
KPW;E	Yes	2.5	130	50.8	56	28.3	26.6	15.5	153	1	20.9	61	10
DREER	Yes	0.7	300	50.5	39	19	39.1	12.5	119	1	37.4	27	15
NOKLL	Yes	1.1	200	65.9	49	12	40.3	10	95	0	43	37	15
ARU	Yes	30.5	220	62.3	19	52	29	6.5	120	1	33	50.5	10
UP120	Yes	24.6	170	48.8	23	33.1	22.9	4.5	129	0	40	57.5	15
ALL&CO	Yes	17.3	50	89.1	43	40	23.9	10	80	0	28.4	65.4	10

BCM	No	8	25	76.9	73	37.7	52.4	27	159	1	19.4	60	5
APU 100	No	6	40	68.8	22	34.2	43.5	10	195	1	17.3	43.4	20
EOI UTP	Yes	10	300	66.8	90.3	29	22.4	5.5	95	0	37	29	10
FLUK	Yes	5	120	39.7	9	16	21.4	10	220	1	51	55	10
500G	No	9	400	29	40	12	33.7	22	129	1	22.4	66	10
GARMI	Yes	11	25	22	39.3	53	40.5	7.5	181	1	32	44.7	15
SSSS	Yes	16	65	91.2	59.2	43	37.9	19	101	0	3	65.1	15
100M	No	7.8	80	44.9	33.8	22	33	15	210	1	15	40.5	10
HK&CO	Yes	9.5	90	72.3	20	21	37.7	13	88	0	7	55.8	5
HARIB	Yes	5	100	78.1	19	33.9	20	10	120	1	18.3	65	15
HMM	Yes	9	110	59.3	11	40.5	18.9	5	67	1	47.4	47.9	15
VJAC	Yes	2.7	25	67.9	17	37.7	26.9	20	130	1	37.7	38.3	20
CHK	Yes	8.9	60	88.2	16.7	33.8	30.4	22	140	1	36.6	67.6	5
LKOD	Yes	11	400	90	34.5	37.9	40.7	15	65	1	40.4	65.5	20
JM	No	17	20	48	30	19	27.1	11	121	1	21	65.5	10
PSSNP	Yes	3	15	27	30.8	20.9	28.2	20	110	0	22	49.7	10
KECS	No	2	20	29.5	39	37.4	14.4	30	194	1	45	51	15
LDKNA	Yes	9	45	57.3	10	16.7	22.9	15.5	88	1	19.9	55	10
DHKTR	Yes	5	75	70	67	30	33.2	7	114	1	12	59	5

OKLKI	Yes	10	100	68	67.3	30.5	16.8	12.5	120	0	23.5	46.6	10
ALFHO	Yes	7	120	59	78.3	32.6	29.9	13	99	1	35	66	5
ROMEN	No	19.3	190	55.7	30	17.9	37.3	12.5	105	1	29.5	45	20
ECOH	Yes	8	130	20.7	28	10.6	32.7	9	135	1	28.4	59	10
TANGO	Yes	1.9	80	44.4	33	22.9	25.3	15	99	0	33	57.6	10
REBUE	Yes	11.1	60	49	44	39	59.8	10.5	145	1	39	45	10
UMPSS	Yes	12	55	30	72	11	42.4	25	125	1	17.5	65.5	15
PPRE	Yes	37	25	82	39.6	26.6	45.1	10.5	149	0	29	45	15
SAMUE	Yes	29	90	75	45	39.1	27.9	3	180	1	20.6	56	10
JAS	Yes	22	120	67	56	43.3	21.9	4	115	0	32.4	67.5	5
YRYAN	No	38	310	92	65	29	21	6	75	1	30	54	15
REEECE	Yes	20	200	71.2	56	337	28.7	7.5	95	0	40	25	15
KANTO	No	19.4	700	44.4	74	24.4	19	19	107	1	23.3	56	20
MARTI	Yes	31.2	220	80.2	80.3	51	8.9	15.5	129	1	43.4	50.5	5
GK&CO	Yes	3	115	93.3	78.9	36.6	55.6	13	182	0	40	55.5	20
PPS LTD	Yes	6.5	60	99	88	40.4	22.8	10	105	0	30	65.4	10
LUC LTD	No	9	40	92	37	20.7	15.8	5.5	200	1	29	65.4	10

MMLD	Yes	3	220	61	8	21.9	35.8	20	105	1	22.4	43.4	15
CCS LTD	Yes	6	29	65.4	9.8	30.2	53.1	22.5	109	0	28.9	34	10
MALEU	No	14	49	68	10	17.8	20.8	15	155	1	27.1	58	5
NIKKON	Yes	15	35	71.3	15	29	32.8	12	130	0	50.2	60.3	20
JSDWT	Yes	2	40	77.1	19.6	37	20.1	20	184	1	40.3	39.4	10
ZMMLTID	Yes	0.7	60	55.5	30.2	32	28.8	30	83	0	10.8	51	10
OSRAM	Yes	2.1	110	51.2	45	25.3	19	15.5	118	1	32.5	55	10
XYSCL	No	3.8	30	57.4	33	59	9.9	7	120	1	21.5	56	15
JBE LTD	Yes	22	45	66	22	42.3	53.4	12.5	199	0	33	46.6	15
PEMEX	Yes	29	80	61	87	44.1	22	13	101	1	25	66	10
PCCW	Yes	1.6	90	58	49	25.9	15.8	12.5	136	0	32.7	57.4	15
PENZIO	Yes	2.2	25	53	44.9	21	35.5	9	98	1	42	59	10
ALUM	Yes	1.7	30	86	66.1	21	54.1	5	145	0	55	57.6	5
NITRO	Yes	1.3	80	63	73	28.8	22.8	10.5	125	0	41	46	20
GOLD	Yes	22.2	100	64.4	76	19	54.3	5	141	1	33.8	65.1	10
MERCU	No	1.4	15	39.5	28	8.9	43	10.5	180	0	22.5	44	10
PLAT	Yes	37	20	33	47	55	22		119	0	11	56	5

SS20LID	Yes	17	90	76	33	22	21.4	9	75	1	11.7	67.5	20
OYA LTD	Yes	12	110	62	29.1	15.8	33.7	7.5	97	1	14.4	55	10
NVD LTD	Yes	9	85	63.5	8.9	35	40.1	13	107	0	29	25	10
NKELT	No	1.4	45	64	19.9	54.1	37.7	15.5	119	0	12	58	10
ROKU LM	Yes	9.2	15	55	40	22.8	32.3	13	182	1	30.3	50.9	15
RR LTD	Yes	15	10	53	33	54	37.9	5	165	0	27.1	45.5	15
SABRE	Yes	22	200	54.9	27	43	20.4	5.5	201	1	48.9	65.4	10
SAMTE	Yes	13	260	61	91	22	18.9	2	105	1	40.3	69.4	5
SUMAZ	Yes	11	320	66	98	21	27.8	12.5	111	1	11	29	15
TB LTD	Yes	0.7	100	74.3	87.3	33.7	32.3	15	148	1	30.3	46	15
TAG LTD	No	9	25	44	20	40.1	40.4	12	125	0	21.5	50.5	20
ACER	Yes	11	35	48	27	37.7	18.8	10	143	1	29	55.5	5
XIA LTD	Yes	10	95	56	60.1	33	42.3	20	180	1	25	62.4	20
ZAMAR	Yes	2	100	86.1	55.9	37.9	27.4	15.5	115	1	32.7	65.4	10
TLUJL	Yes	21	250	46.76	54.4	20	33.7	7	77	1	42	43.4	10
NODFS	Yes	12	1000	17.9	46.9	18.9	25.4	12.5	94	1	50.1	35.5	15

WUTQ	No	10	750	92	60	26.8	51	13.5	109	1	41	58	10
QGWO	Yes	8	260	82.4	9	32	35.6	12.5	129	1	13.3	60.3	5
EPYLN	Yes	2.7	90	28.8	11	40	40.6	9.5	189	0	11.5	39.4	20
YUPIK	Yes	19.9	25	67	28	25.1	20.7	5	105	1	11	60.2	10
NJPP	Yes	17.9	35	62.5	37	29.2	21.8	9	203	1	19	60.6	10
KTP	Yes	3	45	97	8	23	21	19	120	1	2105	52.2	20
SMS	Yes	7	20	77	8.9	20.4	11.1	22.5	177	0	33.1	54.5	10
NOST	No	21	80	83	11.2	18.9	508	15.9	83	1	24.7	66.1	10
TMP	Yes	17	90	55.5	14.9	9	17	10.3	110	1	302	65.4	5
OPTSLT	Yes	12	25	66	16.8	49	14.4	20	120	0	40	44.4	20
CASTOR	Yes	18	100	73.7	31.3	20.4	37.7	27	190	1	48	60.6	15
SKSLTD	Yes	2.1	90	65.3	29.9	29.1	28.6	16	155	1	30.6	44.8	20

Appendix E: Ethical approval form:

University of East London

Dear Roselin

Application ID: ETH1819-0102

Project title: Cloud manufacturing model to optimise manufacturing performance–an empirical study

Lead researcher: Mrs Roselin Francis Xavier

Your application to University Research Ethics Committee was considered on the 13th of March 2019.

The decision is: **Approved**

The Committee's response is based on the protocol described in the application form and supporting documentation.

Your project has received ethical approval for 2 years from the approval date.

If you have any questions regarding this application please contact your supervisor or the secretary for the University Research Ethics Committee.

Approval has been given for the submitted application only and the research must be conducted accordingly.

Should you wish to make any changes in connection with this research project you must complete 'An application for approval of an amendment to an existing application'.

The approval of the proposed research applies to the following research site.

Research site: UK

Principal Investigator / Local Collaborator: Mrs Roselin Francis Xavier

Approval is given on the understanding that the UEL Code of Practice for Research and the Code of Practice for Research Ethics is adhered to.

Any adverse events or reactions that occur in connection with this research project should be reported using the University's form for Reporting an Adverse/Serious Adverse Event/Reaction.

The University will periodically audit a random sample of approved applications for ethical approval, to ensure that the research projects are conducted in compliance with the consent given by the Research Ethics Committee and to the highest standards of rigour and integrity.

Please note, it is your responsibility to retain this letter for your records.

With the Committee's best wishes for the success of the project

Yours

Fernanda Silva

Administrative Officer for Research Governance

Research, Research Degrees and Ethics Subcommittee (RRDE)

Email: **researchethics@uel.ac.uk**