CRANFIELD UNIVERSITY

Michael O Ochwa

Conceptual Simulation Design

SCHOOL OF APPLIED SCIENCES

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ABSTRACT

The work presented in this thesis considers the issues related to the design and implementation of the rotor blade production facility at Rolls-Royce. The volume production of this component will be significantly higher than Rolls Royce has ever delivered on similar projects. As a result, a future factory consisting of process lines and manufacturing cells will be built. The issue considered includes the evaluation of various factory designs and layout techniques that will improve production flow, optimal capacity utilization, and minimum work-in-process and lead-times. The subject of manufacturing cells verses machine utilization was also considered. This factory design and selection analysis was supported by extensive research comprising literature review and simulation study of various manufacturing layouts including cellular, job-shop type functional layout and hybrid configurations. Therefore, this study provides a basis to properly carry out analysis of the current Rolls-Royce production facilities and subsequently the preliminary conceptual simulation design of the future factory to manufacture L-Generic-blisk and F-Generic-blisk drive engine compressor Generic-blisk. A number of cell and flow-line design concepts were analysed with a succession of flexible Witness models (configured and driven by Microsoft Excel) and used to analyse the flow and productivity, to support a sustained growth in production volumes and maturation of process.

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In addition, I would like to thank my family for their endless support throughout my life and career. To my brothers and sisters in Christ, much appreciation for having faith in me, and the support you have shown throughout this period.

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GLOSSARY OF TERMS

CI	Continuous Improvement
CM	Cellular Manufacturing
CMM	Coordinate Measurement Machine
DES	Discrete Event Simulation
FC	Functional Configuration
FIFO	First In First Out
GT	Group Technology
HB	Hybrid Configuration
IAT	Inter Arrival Time
IBRs	Integrally Bladed Rotors
IPPD	Integrated Product and Process Development
JSF	Joint Striker Fighter
LA	Line Analysis
LFW	Linear Friction Welding
M/C	Machine
MPC	Manufacturing Planning and Control
OE	Original Equipment
PFA	Production Flow Analysis
PPM	Process Performance Measurement
RAS	Royal Aeronautical Society
ROCE	Return on Capital Employed
RR	Rolls-Royce
RRPS	Rolls-Royce Production Systems
SAP	Systems Applications and Products
SLP	Systematic Layout Planning
Takt	A German word for ‘rhythm’ or ‘pace’
VSM	Value Stream Mapping

1 Introduction

Rolls-Royce is a global manufacturing company that specialises in four market sectors, namely, civil aerospace, defence aerospace, marine and energy. Its operation is spread over fifty countries and employs up to 36,200 employees. Its corporate strategy has been geared towards developing all the four sectors at equal levels. Last financial year it reported a remarkable increase in sales, which amounted to over £7.2 billion. There is also increased in revenue from supplying Original Equipment (OE) to after sales market (Rolls Royce, 2005).

Since its inception, Rolls-Royce's main goal has been and still is to develop a competitive strategy against competitors and to embark on producing products and services that compete in all market sectors. Rolls-Royce looks at technological advancement as the yardstick to fen-off competition. To remain competitive in the Global Economy as any other competitors, Rolls-Royce strives to continually reduce cost, increase performance and reduce lead-times in order to remain competitive.

Rolls-Royce is renowned worldwide for the production of Aircraft Engines mostly for the major aircraft manufactures. Lately, according Flight International Journal (2007), the Group has developed Trent 900 to support the Airbus A380, the Trent 1000 to support the Boeing 787 and in partnership with Pratt and Whitney. With General Electric it supports the Lockheed-Martin Joint Striker Fighter for the F135 and F100 Engines.

1.1 Overview of the Industrial Problem

Rolls-Royce involvement in development and production of Joint Striker Fighter engine delivers many challenges to the business. For instant, current production facilities for integral bladed rotors manufacture cannot meet the projected volume. Demand forecast for the Generic-blisk, over the next 5-10 years presents a significant growth in capacity for the Group; moreover Rolls-Royce is planning to build new facilities to support these projects.

To deliver the project, a number of factory design layout concepts are being considered, and a family of flexible Witness models (configured and driven by Microsoft Excel) has been created, analysed and compared to aid in reaching a realistic conclusion. The study was focused on the material flow, productivity, investment appraisal, (machines & space) and manning to support a sustainable growth in production volumes and maturation of the process. The factory layout design will incorporate a hybrid configuration of cellular and job-shop type layout. This combination of cellular and functional configuration is a trade-off in manufacturing design to arrive at optimal solution to the problem.

The advancement of the Generic-blisk production facilities is one is attracting a considerable capital investment. Rolls-Royce has currently set-up a pre-production facility in two of their sites in Nottingham, Hucknall and Annesley, which are now supporting the development of the L-Generic-blisk and F-Generic-blisk drive engine compressor Generic-blisk manufacturing.

The major focus of the Generic-blisk manufacturing is in the welding process. The welding technique is very complex and requires many production hours and skills. However, the technology employ in the manufacture of Generic-blisk offers greater benefits than the traditional bladed rotor, where the blades are slotted into the disk.

In general, the integral bladed rotor manufacture is time consuming, complex and requires a great deal of skills. This complexity leads to lack of uniformity in the machine/equipment process utilization level. The issue is how to incorporate these special operations within the process route without significantly affecting the component flow within the factory.

1.2 Thesis Aim and Objectives

The aim of this research study has been to evaluate and demonstrate designs for future Generic-blisk factories capable of fulfilling high volume demand. In order to achieve the above aim, the main research objectives have been to accomplish the following:

- To produce a conceptual simulation design of integrally bladed rotor for Generic-bisk engine factory.
- To evaluate the current models for the future civil and military Generic-blisk factories using Witness simulation.
- To evaluate various manufacturing and assembly methods including cellular, Job-shop, hybrid, designs (to be considered).
- To test Rolls-Royce manufacturing Engineering process for how to deploy virtual manufacturing.
- To make recommendations as to how best to use Witness simulation for production planning to meet high volume demand.

1.3 Research Scope

The scope of the research is to study the actual process of the current Generic-blisk pre-production facility. To gather available data on Generic-blisk manufacture; analyse for the conceptual simulation design work. Finally to produce a conceptual design of witness simulation model and present the results.

1.4 Thesis Structure

This thesis is presented under different chapters for ease of clarity. In Chapter 2, Rolls-Royce industrial context is discussed. In this section Rolls-Royce products, marketing strategy (ies) and the manufacturing facilities is discussed at length. More importantly too, the engine compressions systems was discussed.

Literature is reviewed at in Chapter 3. A lot of data and material was gathered from textbooks, journals and Internet websites. To gain an in-depth knowledge on the subject matter a number of visits were made to Rolls-Royce plant and gathered some data.

In Chapter 4, the research methodology is discussed. In this chapter, details of research design, research instruments and methods of result analysis are also discussed.

Manufacturing systems overview regarding blade manufacturing, performance measurements, capacity planning, Rolls-Royce production facilities and welding methods for Generic-blisk have been discussed in Chapter 5. Rolls-Royce Manufacturing Planning & Control (MPC), Generic-blisk manufacturing process and current shop-flow layout and flow also formed part of this chapter.

Chapter 6 cover the simulation design and data collection. The model design was done with Witness as the simulation package. This chapter clearly shows the routes, construction and the logic. In-depth discussions on Rolls-Royce use of Excel-Witness configuration have been presented. A number of simulation models; different factory layouts and details of all progress and how the final model was chosen are also presented.

Simulation and scientific analysis of result is covered in Chapter 7. Here data that leads to the conclusion and recommendations are presented in logical manner. Final results were arrived at after carefully analysing the data generated in Chapter 6.

Finally, Chapter 8 discusses the conclusions arrived at and presents the recommendations thereafter.

2 Industrial Context

2.1 The Company

Rolls Royce manufactures a range of product in their facilities around the world for both civil and military market. The Group's global market portfolio and position are listed below according to (Rolls-Royce, 2004).

- Number one military aero engine manufacturer in Europe.
- Number two military aero engine manufacturer in the powering approximately 25% of the world's military fleet.
- Rolls Royce supplies engines to many more customers (160) in more countries (103) than any other manufacturer.
- Royce-Royce has whole engine design, engineering and manufacturing facilities in the UK (Bristol), Germany (Dahlewitz) and the US (Indianapolis).

2.2 The Main Products and Markets

Rolls Royce's Annual report for 2006 reported a strong market position in each of the four market sectors.

a) Civil Aerospace

Civil aerospace is the largest of all the four sectors grossing 3.8bn (2006), it is now established as the world's second largest engine maker overall, and leading in large turbofans and business jet.

The Group predicts a 20 year market outlook, which covers all range of their aircraft; with 114,000 engines, worth over US$600 billion will be required, powering 51 commercial aircraft and business jets (Rolls-Royce, 2007).

b) Defence Aerospace

With annual sales of £1.569 million in 2006, the Defence Aerospace is the number one military aero engine manufacture in Europe and number in the two in the world. The company's latest report indicated that the defence aerospace continues to be a profitable and growing business. With a wide range of defence engine programmes at all stages of the product life cycle, supported by a rapidly growing services business. The underlying service revenue accounted for 53% of defence sales in 2006.

In addition, Rolls-Royce has been involved in a major combat aircraft programme, supplying hardware and technical expertise. In July 2002, the GE (General Electric) Rolls-Royce Fighter Engine Team joint venture was formally created to develop the “interchangeable” engine for Lockheed Martin F-35 Joint Striker Fighter, with a 40% share to Rolls Royce of the JSF programme.

The Group forecast that demand for military engines would be worth US$180 billion over the next 20 years (Rolls-Royce, 2007).

c) Marine

Rolls-Royce is a world leader in the marine propulsion systems, offering a unique set of product and services for both naval and commercial sectors.

With an annual turnover of £1300m in 2006, all the marine business segments, offshore, merchant, naval and submarines are performing well. Currently Rolls-Royce has equipment of over 20,000 vessels and sales and services in 34 countries.

The Group forecast demand for marine propulsion systems of US$180 billion over the next 20 years (Rolls-Royce, 2007).

d) Energy

The Energy sector is the smallest of all the four and over the years has served more than 15,000 units of customers in nearly 120 countries investing mainly in the oil and gas industry. The last financial year has indicated a small lost due to a huge investment in the fuel cell technology The Group’s 20 year forecast values the total aero-derivative gas turbine sales in the oil and gas and power generation sectors at US$70 billion (Rolls-Royce plc, 2007).

2.3 The Manufacturing Facility

Continuous improvement (CI) in operation excellence from strategic decisions on what to make or buy through the growing efficiency of its domestic facilities, to the streamlining of its supply chain, which provides around 70% of an engine’s constituent parts, is key strength to Rolls-Royce business operations (Sky control, 2007).

In April 2004, Rolls-Royce announces it was to invest £100 million in four new facilities, which are now in various stages of development. These sites are:

- Hucknall – opened a new Combustion Systems in October 2005,
- Derby – 2 x Compression Systems facility,
- Bristol – Turbine Systems/Components Services facility.

Rolls-Royce gained a valuable experience in the ‘focused factory’ after successfully pioneering a simplified work flow, ‘single-piece’ manufacturing concepts in 1999, when the company invested £45 million in turbine blade facility in derby, prior the 2004 project, and another £85 million investment in facility built at Inchinnan, near Glasgow, to replace the Hillington factory, which was closed in 2005 after operating for 60 years (Skycontrol, 2004)

Rolls-Royce has production systems tool (RRPS), which draws on a vast wealth of best practice accumulated across the company; with the tool, new facilities are planned, built, equipped rapidly. The system provides information on the latest in factory and visual workload management methods, etc.

2.3.1 The Compression Systems

The compression system is the largest business unit within the Global Gas Turbine operations. Based in the UK, with operations globally, supporting both Civil and Defence customers, this business function is responsible for the design and manufacture of key fan and compressor components. Rolls-Royce Systems UK locations and functions are listed below:

2.4 Chapter summary

This chapter looked at the industrial context; the main functions and product portfolio of the Rolls-Royce, the facilities, pass, current and future investment, with a view to understand the Groups market position. The brief study has provided the researcher with vast knowledge of the Groups business operation, technological advancement, and more importantly, the product range.

3 Literature Review

3.1 Introduction

This chapter reviews the literature and previous work carried out on factory design and process improvement. Moreover, facility layout, the type of manufacturing layouts, assembly cells and flow line are also discussed. The design and manufacture of integrally Bladed Rotor (Generic-blisk) will also be reviewed and presented. Later in the chapter, virtual manufacturing (VM) will also be discussed, especially the application of discrete-event simulation (DES), particularly Witness in manufacturing.

3.2 An Outline of Factory Design

There are many factors that drive an organization to reorganize its manufacturing operation to achieve a new milestone. These includes: expansion, new production introduction, space & equipment utilization, factory automation, decreasing inventory cost, and operation cost. According to Hyer and Wemmerlov (2002), factory planning encompasses three related areas: 1) identifying opportunities for restructuring the work organisation into cells; 2) designing a new factory layout to accommodate cells; and 3) modifying the firm's management systems to align them with the new work organisation and layout. However, for an existing company looking for change, the following must be examined:

- What types of analysis tools and techniques are available to project teams assigned with the task of reviewing and upgrading factory performance?
- Is it possible or desirable to identify opportunities for focused manufacturing (including cells)?
- What techniques are available for designing cells? And what types of goals and constrains should you apply to that process?
- What is the process of rethinking the factory layout after the conversion to cells?

Focusing on automation, Colvin (2001) lists the following criteria to answer factory design issues:

- Process definition
- WIP Distribution (Production and Test)
- Theoretical and Factory cycle time
- Expected product change
- Factory throughput requirements
- Expansion scenarios
- Operation sequencing and plan for automation and scheduling to optimise the manufacturing process.

Conversely, Hyer and Wemmerlov, (2002) list the possible types of analysis that can be performed during factory planning:

1) ***Confirming the course***
    - Classification of project scope, metrics, and associated goals
2) ***Understanding the current situation***
    - Family grouping analysis
    - Product-volume analysis
    - Performance analysis
    - Resource/technology analysis
    - Capacity-load and bottleneck analysis
    - Space analysis
    - Material-flow analysis
    - Process flow analysis (process mapping)
3) ***Modifying product and part families***
    - Product rationalisation (standardisation) analysis
    - Make/buy/subcontract (outsourcing) analysis.

3.3 Material Flow and Facility Layout

The basic objective of layout is to ensure a smooth flow of work, material, and information through the system. According to Santos *et al,* (2006), “factory layout improvements typically occur more than one time during a factory’s life, and the study of plant layouts seeks the optimal location for all the production resources.”

The underlying requirement of an effective material flow and facilities design is to achieve the following objectives:

- to minimise material handling;
- to utilise space efficiently;
- Provide flexibility and easy adaptation to the process, and etc.

A good layout will also facilitate communication and interaction between shop floor workers, between worker and their supervisors, etc. security and safety is also achieved by good layout, as well as material movement within the cell or flow line, and people. The three basic types of layouts are:

a) Process layout
b) Product layout and
c) Fixed-position layout.

The subsequent type (hybrid) of layout processes to the traditional factory layout designs, which combines some aspects of the traditional layout are:

d) Cellular,
e) Flexible manufacturing systems, and
f) Mixed model assembly lines.

3.3.1 ***Process Layout***

Also called functional layout, this process the machines are grouped into department according to their function. This type of process is common with companies that specialises in made-to-order type if product.

3.3.2 ***Product Layout***

Here the machines are grouped according to the product manufacturing sequences. Depending on the main activity of the production line, these layouts are called *manufacturing assembly lines.* This process is mainly used in the production of high volume components, and it has many advantages such as: large batches can be produced inexpensively, materials handling in minimal, in-process materials are minimised, it is easy to control these systems, and automation is more achievable and justifiable (Santos *et al,* 2006).

3.3.3 Fixed-Position Layout

In this type of layout, the product is stationary throughout the product process; the needed resources are brought to the work-piece. This process is used in the production of large products such as aircraft, ships or any other product, which is large and difficult to move.

3.3.4 Cellular Layouts

Cellular layouts attempt to combine the flexibility of a process layout with the efficiency of a product layout. Based on the concept of group technology (GT) utilises the concept of divide and conquer and involves the grouping of machines, processes, and people into cells responsible for manufacturing or assembly of similar parts or products. Cellular Manufacturing is now an established international practice to integrate equipment, people, and systems in “focused factories,” “mini-businesses,” or “cells” with clear customers responsibilities and boundaries (Irani 1999).

Cellular Manufacturing is discussed later in this and subsequent chapters.

3.3.5 Flexible Manufacturing Systems (FMS)

Traditionally, production facilities have two conflicting objectives: flexibility and productivity. Flexibility refers to producing a number of distinct products in a job shop environment where opportunities for production variability exist (Raouf and Ben-Daya, 1995).

Slack *et al*, (988), describes flexible manufacturing systems as “a computer controlled configuration of semi-independent work stations connected to automate material handling and machine loading”.

3.3.6 Mixed Model Assembly Lines

Also known as hybrid layouts, it is a type of process, which combines elements of some or all of the basic layouts, or use, the ‘pure’ basic layout types different parts of operations (Slack *et al*, 1988).

Some of the factors to be considered in the design of mixed model layout include the following: (1) line balancing; (2) flexible workforce; (3) modelling sequencing and (4) the shape of the process line.

3.4 Comparison: Cellular Vs Job Shop Manufacturing

3.4.1 *Cell Manufacturing*

Many authors have different definitions of cells. According to Hyer and Wemmerlov (2002), a cell is a group of closely related workstations where multiple, sequential operations are performed on one or more families of similar materials, parts, components, products, or information carries. The notion of a cell is that must contain a small group of resources, human and technical, *dedicated* to the processing of a set of similar parts or products.

A manufacturing cell is a cell whose main purpose is to physically process, transform, transmit, and add value to materials whose end state are products or components.

Singh and Rajamani, (1996) define a manufacturing cell as " a group of workstations, machines or equipment arranged such that a product can be processed progressively for one workstation to another without having to wait for a batch to be completed or requiring additional handling between operations". Cell manufacturing has been proven advantageous, and many authors believe, the smaller the cell the benefit is to in terms of: (1) social interaction; (2) information flow; (3) control or management of cell; (4) material handling perspective and dedication.

Burbidge (1984) stated that cellular manufacturing has the main characteristic of group technology; all organizational units complete specified products or sets of similar components, through the stage of processing with which they are concerned. Typical components of a manufacturing cell composition are as follows:

- Machining centre
- Material or part handling equipment (robots, overhead crane, etc)
- Tools and tool-room
- Buffer or part storage area
- Machine inspections and monitoring devices.

Notable advantages of cellular manufacturing are listed below:

- Capacity effects
- Multifunctional employees.
- The social effect of group work.
- An environment for job expansion and learning
- Shorter setup and smaller lots.
- Family based scheduling.

3.4.2 *Job Shop (Functional Layout)*

Job shop groups *similar equipment* into functionally specialised units in order to manufacture a variety of *dissimilar parts* that may follow highly variable routings. The flexibility of this arrangement, i.e., the ability to process parts of products regardless of their routing sequence and production needs, is the greatest advantage of a job shop.

The advantage of the cell system is that in the area of automation and highly mechanised material handling systems, such as using robots, conveyor, etc; the efficiency is easily achievable. The drawback is that the cell has less flexibility than a job shop to adapt to labour, tailored to cell products, and to the desire to avoid going outside the cell to complete operations

Figure 3-1 and 3-2 illustrate a schematic view of a typical a functionally organised manufacturing area and a manufacturing area organised with cellular principles, respectively.

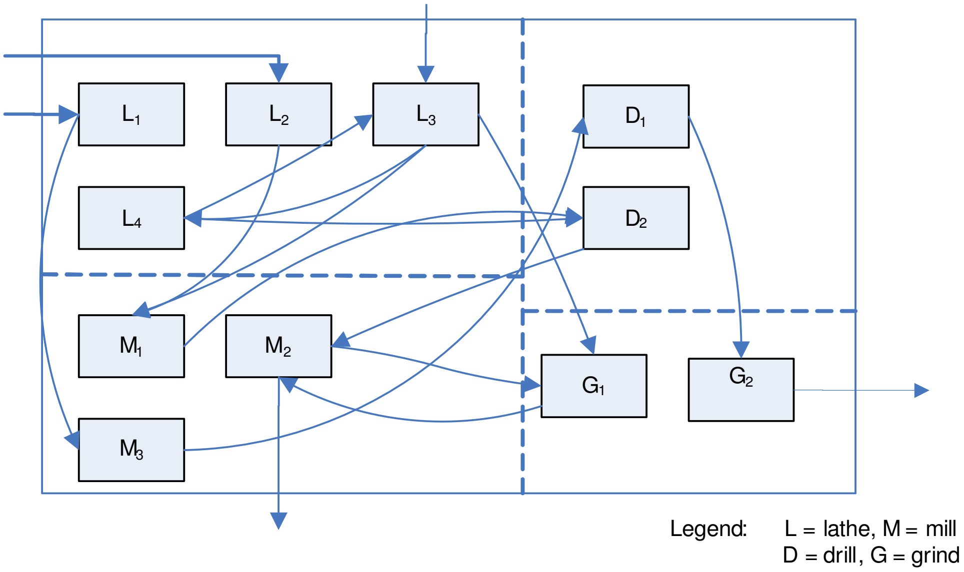


Figure 3-1: Functional Layout (source: Hyer and Wemmerlov, 2002)

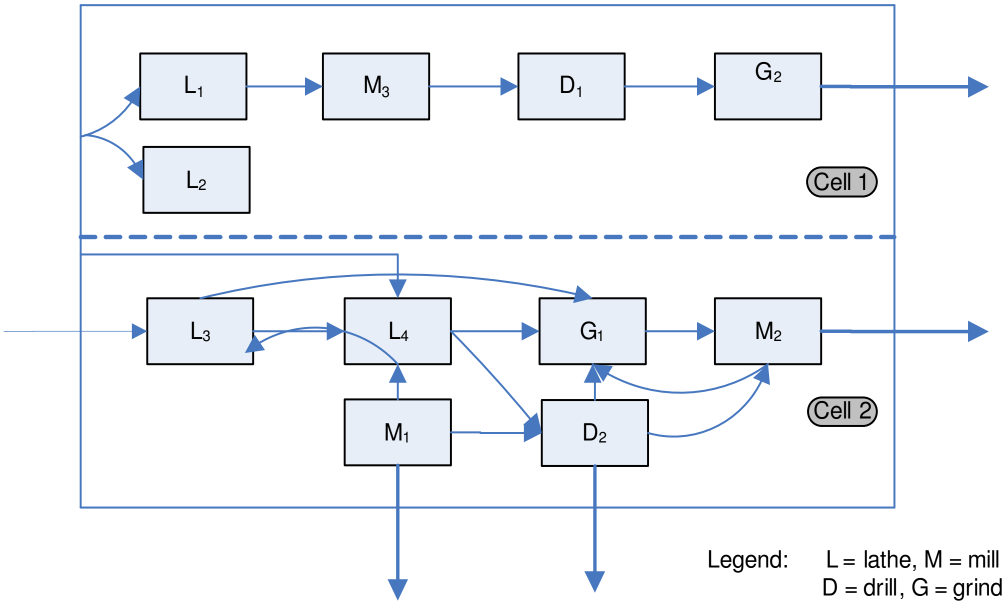


Figure 3-2: Functional Layout (source: Hyer and Wemmerlov, 2002)

3.5 Designing Factory Layout

Designing a new factory or improving an existing one involves many aspects of manufacturing to consider. The consideration is for the machines, material and layout for flow. Rother and Harris (2001) believe that processes of any kind require the coordination of: man, machines, materials and methods (also known as the 4 Ms). To better understand the process and thus to achieve the aim, the designer should determine whether the following: can the available equipment meet *Takt* time, how much automation is required, and the efficiency of the worker in regards to the layout.

Takt is a German word for “rhythm” or “pace”. *Takt* is also an important term in manufacturing systems design. “Takt time is the allowable time to produce one product at the rate a customer demands” (Santos *et al,* 2006).
When creating a cell, it is vital to know that the machines being grouped actually perform to the required *takt* time. To achieve this, Rother and Harris (2001) state that, each machine must be able to complete its cycle on each part within takt time. Hence, the ‘effective cycle time’ of each machine should be considerably less than takt time it continuous flow is to be achieved.

Many authors consider automation as being the most visible aspect of factory layout. Slack *et al, (*1998) states two benefits of increasing the degree of automation in a process technology; it saves direct labour cost; and reduces variability in the operation.

Guerindon (1995) argues that automation is costly, it erodes short-term profits and in some cases companies do not achieve the results they had anticipated. Rother & Harris (2001) also argue that, when utilised properly automation can achieve an efficient and flexible continuous flow of material. Otherwise, if designed or used inappropriately, automation can also inhibit flow.

3.5.1 Machine Utilisation

Various authors have discussed machine utilisation; Hyer and Wemmerlov (2002) describe machine utilisation as simply the relationship between the time it takes to process an average batch and time available between successive arrivals of batches, in other words the ratio of the required capacity to the available capacity.

Machine utilisation can also be a direct measure of productivity capacity; taking account of the time when the machine is working on the part as well as when is it idle, i.e., waiting for a part in the queue, loading, set-ups or machine breakdowns. Machine utilisation rate will vary accordingly, and not remain at the same level. In bladed rotor manufacturing, for example, presents a huge distinction in the machining operations.

Burbidge (1979) believes that, new attitude towards the use of machinery is required since we can not have an ideal system; hence it is necessary to accept lower utilisation levels in order to achieve faster material flow and that machine utilisation should not be the focus. Most manufacturers set their machine utilisation between 80 and 90 percent. It is imperative that the utilisation level does not exceed 100 percent has this would mean that the part arrive time will exceed machining time, leading to undesirable level of WIP.

3.6 Physical Layout of Process

Physical layout of the process is one of the most important aspects of factory design (cell design). There are many approaches and methodologies in designing a factory/cell, the notable one is by Rother & Harris (2001), who believe that an elegant tactic of cell design is, "Arrange the machines, workstations, and material presentation devices as if only one operator makes the product from beginning to end, even if you never run the cell this way".

The goal is to design a process that a worker can move through it and perform the entire work element efficiently. This can be achieved by designing a process that avoids isolated islands of activity, minimised inventory accumulation between processes, eliminates excessive walking, removes obstacles in walking paths, and brings the people-driven, value-creating steps as close to one another as possible.

3.6.1 Production Flow Analysis

Production flow analysis (PFA) is a technique, based on an analysis of the data contained in component route cards, which is used to plan the change from process organisation to product organisation (or Group Technology), in component processing workshop or factory (Burbidge, 1984).

A factory that is arranged on the basis of a process organisation or according to functional groups or processes; each organisational unit specialising in particular process, will have the following disadvantages:

1. Long throughput times – leading to high investment in stocks and WIP and lengthy delivery times.
2. Provides poor basis for Automation- any change to automation involves many different units of organisation.
3. Provides poor basis for quality – many people must co-operate to achieve high quality.

This type of arrangement can be improved; eliminating the disadvantages, by introducing group technology (cellular manufacturing). Known for its effective method of rationalising of the layout and utilisation of small to medium size batch manufacturing facility into groups, GT is considered a methodical approach that encompasses and economically utilises batch/job-shop or functional arrangement, comparable to mass production.

Creation of the techniques for finding parts and machine family is one of the key characteristics of Group Technology and cell manufacturing. Because parts and machines can be classified into families and groups, significant cost is reduced through waste and time reduction. For this reason many companies are implementing GT to safe time and money. The primary objective of GT is that, similar operations should be done similarly; this includes: (1) machining; (2) assembly; (3) production control; (4) process planning; (5) product design; and (6) process design. The aim of Group

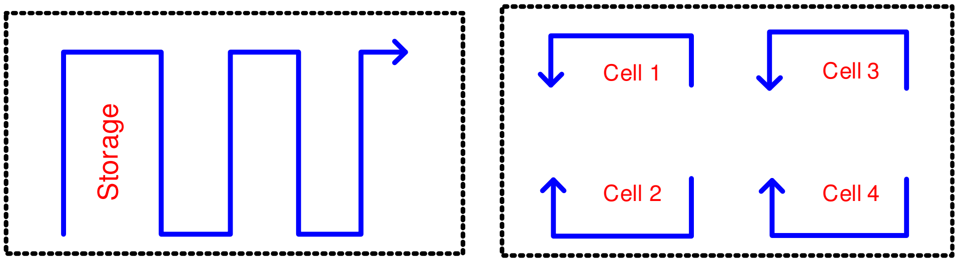
Technology is to allocate the manufacturing facility into a section or a group of cells or machines (Burbidge, 1996).

3.6.2 Line Analysis

Line analysis is a sub-technique of PFA, which is used to analyse the flow of materials between the machines and other work centres in groups. The objective of LA is to provide the information needed to plan the best plan layout for the group (Burbidge, 1996).

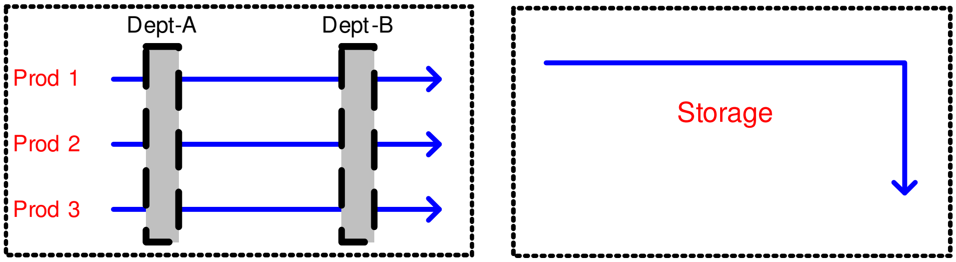
3.6.3 Material Flow Analysis

Material flow is a primary activity that drives a factory layout. Good layouts have smooth and short flows with a minimum of backtracking and crossover (Andradottir *et al*, 1997). Figure 3-3 below illustrates some of the layout design available for different product families:



S-CURVE LAYOUT

U-SHAPED CELLS



STRAIGHT LINE MANUFACTURING
WITH CROSSWISE DEPARTMENT

L-SHAPED MANUFACTURING
WITH CENTRAL STORAGE

Figure 3-3: Layouts Configurations (source: Andradottir et al, 1997)

3.7 Plant Layout and Flow Analysis

There are many problematic issues associated with the manufacturing plant layout selection and implementation. These issues are related to machine location, change in design of a product, additional or removal of a product from the production line, increase/decrease in the product volume, change process, and other factors including health and safety required and law.

According to (Francis, 1974), plant layout problems may also develop because of gradual changes over time that finally manifest themselves in term of bottlenecks in production, crowded conditions, unexplainable delays and idle time, backtracking, poor housekeeping, excessive temporary storage space, obstacles to materials flow, failure to meet schedules, and high ratio of material handling time to production time.

Figure 3-4 below illustrates the communication link among product, process and scheduling, and layout design. It is used to coordinate the product, process schedule, and layout design decisions.

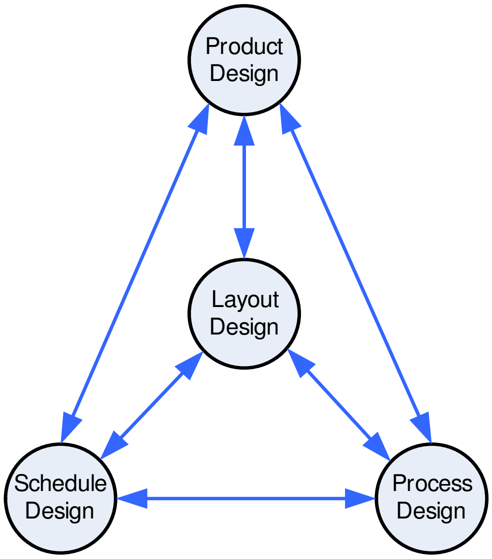


Figure 3-4 : Communication Links (source : Francis, 1974)

3.7.1 Process Selection

When faced with the task of choosing the best process for a factory layout, there are many methods available; the most common ones being ranking procedure and the factor analysis procedure. These two procedures involve a comparison of layout alternatives for each factor (Francis, 1974).

Factors to be considered include the following:

1. Fit with company organization structure.
2. Ease of future expansion.
3. Flexibility of layout.
4. Material-handling effectiveness.
5. Space utilization.
6. Working conditions; safety and housekeeping.
7. Ease of supervision and control.
8. Appearance, promotional value, public or community relations.
9. Equipment utilization.
10. Ability to meet capacity or requirements.
11. Savings, payout, returns, profitability.

3.7.2 Systematic Layout Planning (SLP)

The notion of SLP was developed to aid facility and layout design. It is technique developed by Muther (1955), and over the years has gained a wide recognition among many authors and industrialists. The procedure is presented graphically in Figure 3-5 below.

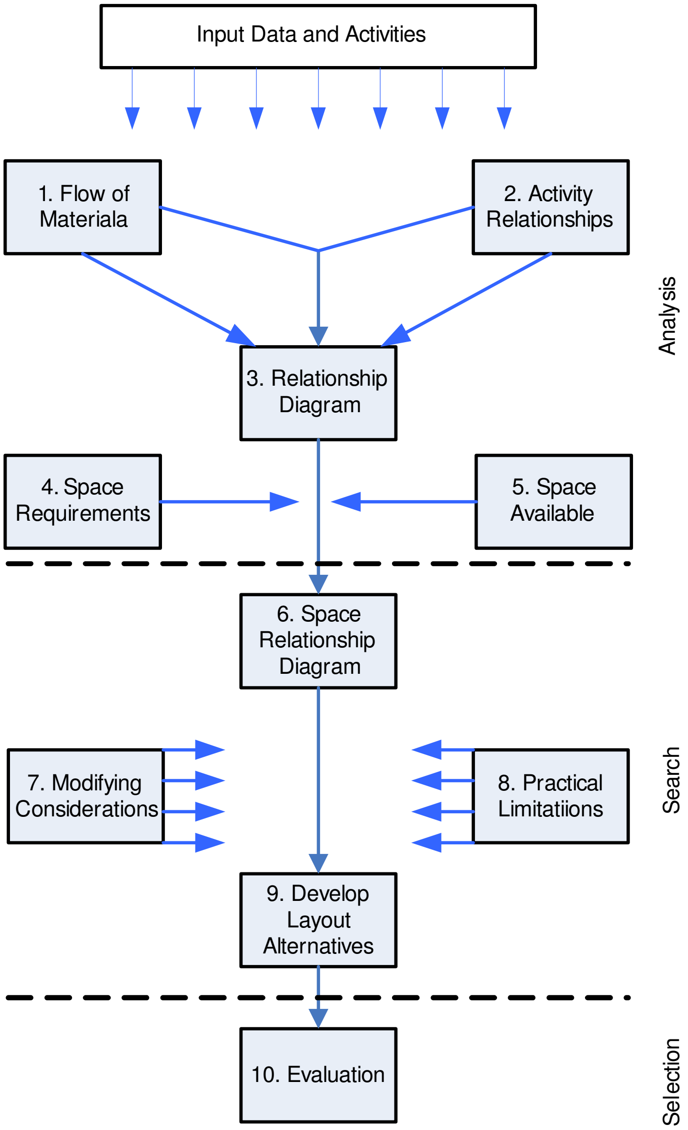


Figure 3-5: Systematic Layout Planning Procedure (source: Francis, 1974)

Here we see that once the appropriate information is gathered, which forms a significant part in the activity of plant for layout analysis, a flow analysis can be combined with activity analysis to develop the relationship diagram. The space considerations, when combined with the relationship diagram, leads to the construction of the space-relationship diagram. Based on the space-relationship diagram, modifying considerations, and practical limitations, a number of alternative layouts are designed and evaluated (Francis, 1974).

3.7.3 Flow Activity Analysis

Francis (1974) describes as “some quantitative measure of movement between department and activities, whereas activity analysis is primarily concerned with the no quantitative factors that influence the location of departments or activities”.

Some of the factors that affect flow patterns are given by Apple (1973) are listed below (Francis, 1974)

- External transportation facilities.
- Number of parts in product.
- Number of operations on and sequence of operations on each part.
- Number of subassemblies.
- Number of unit to be produced.
- Amount and shape of space available.
- Types of flow patterns.
- Product verses process type of layout.
- Material storage
- Desired flexibility
- The building.

3.7.4 A Relationship Chart

Relationship chart is used as an alternative method of indicating the relative importance of the relationship between work centres. According to Slack *et al* (1998) a relationship chat indicates the desirability of pairs of work centres being close to each other. Table 3.1 is a typical relationship chat used in process design.

Table 3-1: Relationship chart (source: Slack *et al*, 1998)

CODE	CLOSENESS IS…
A	Absolutely necessary
E	Especially Important
I	Important
O	Ordinary closeness
U	Unimportant
X	Undesirable

3.8 Virtual Manufacturing (VM)

Based on VM Technical Workshop, (1994), VM is described as the integration of enabling technologies, and the three paradigms of Virtual Manufacturing:

***Design-Centred VM*:** "provides manufacturing information to the designer during the design phase. VM is the use of manufacturing-based simulations to optimize the design of product and processes for a specific manufacturing goal such as: design for assembly; quality; lean operations; and/or flexibility".

***Production-Centred VM*:** "uses simulation capability to manufacturing process models with the purpose of allowing inexpensive, fast evaluation of many processing alternatives. VM is the production-based converse of IPPD which optimizes manufacturing processes, potentially down to the physical level".

***Control-Centred VM*:** "is the addition of simulations to control models and actual processes, allowing for seamless simulation for optimization during the actual production cycle. Virtual manufacturing is described as the integration of enabling technologies with traditional (example: design, tooling, process plans, business systems, etc.) and new (virtual reality, artificial intelligence, design analysis applications, smart agents, etc.) manufacturing tools.

This philosophy and tool that integrates all the technological functions together can dramatically reduce lead times and cost by getting the right information to the right people at the right time with increase speed and accuracy of decisions. "

According to report Royal Aeronautical Society, (1996), the key virtual manufacturing capabilities include:

- easy to use graphical interface to allow users at all levels to participate
- workplace ergonomics modelling and analyses
- fabrication and assembly modelling and sequencing for complex products and systems
- facility planning, layout, and robotic offline programming
- NC machining centre simulation and verification
- Immersion and training in the simulation environment

A typical VM tool will contain an integrated suite, which allows users of all level to interact and participate in the Virtual Manufacturing environment.

3.8.1 Benefits of Virtual Manufacturing

Employing virtual manufacturing will provide the benefit of foreseeing the manufacturing problems and hence illuminating them at an early design stages is key benefit that VM can offer. Other benefits include:

- Elimination of waste,
- Ability to optimise the entire manufacturing or machining process without actually committing to any investment,
- Low investment cost; cost only limited to the actual software,
- Simulation of complex operations,
- Virtual prototyping.

3.9 Virtual Manufacturing Tool (Factory Design)

3.9.1 FactoryCAD

FactoryCAD works in conjunction with AutoCAD to help manufacturers create detailed 3D models of their plats. The software accelerates the process of plant layout by enabling users to design with 'smart objects' that represent virtually all the resources used in a plant, from conveyors, mezzanines, cable trays, fencing and cranes to material handling containers and operators. It has a user-interface, which contains drop-down menus making it easier to place on the layout. It also contains facilities for structural work, detailing, block/symbol management and space planning (manufacturingtalk, 2006)

3.9.2 Factory Flow /Factory Plan

FactoryFLOW integrates actual facilities drawings and material flow paths with production and material handling data. Evaluations are based upon the quantity-distance product. FactoryFLOW can measure distances according to Euclidean distance, rectilinear or actual path methods. It provides from-to chart, distance-intensity chart, congestion analysis and other tools. Process routing data can be imported directly from Excel spreadsheets. Factory Plan is a layout-planning tool based upon Systematic Layout Planning (Carrie and Eghlio, 2001).

3.9.3 Simulation Modelling (Discrete Event Simulation)

Discrete event simulation (DES) concerns the modelling of a system as it evolves over time by a representation in which the state variables changes instantaneously as separate points in time (Law and Kelton). Discrete event systems (DES) are dynamic systems, which evolve in time by the occurrence of events at possibly irregular time intervals. DES abounds in real-world applications. Examples include traffic systems, flexible manufacturing systems, computer-communications systems, production lines, coherent lifetime systems, and flow networks (Arsham, 1996).

Today manufacturers are expected to rapidly react to changes in market demand, and at the same time produce a variety of high quality product at low cost and harness the embryonic product & production technologies (Beal and Nurse, 1987). The need to maintain and improve competitiveness is a challenge that manufacturing companies continually face. Competition is increasing in virtually every market sector, particularly from the Pacific Basin countries. To survive, companies will have to make investments in new and existing facilities that will cut costs, reduce lead times and improve quality (Aitchison and Kay, 1991).

As a tool for describing the behaviour of real-world systems over a given period, simulation modelling can be used to analyse variety of practical problems. According to Aitchison and Kay (1991), simulation models can be developed that have characteristics of that real system and can be used to analyse those systems, to determine if future investment will achieve the desired result before they are adopted. Simulation modelling presents the following benefits:

- Offers improvement to be made on a virtual environment;
- Offers to analyse and optimise the entire manufacturing process;
- Offers cost effective investment in capital and production assets;
- Offers faster plant change;
- Offers risk reduction due to its virtual nature.

3.9.4 Witness as Software

Witness is a computerised discrete-event simulation system sold by Lanner that is designed for modelling manufacturing operations. It utilises a graphical interface, menus and high-level elements so a non-specialist user can build, validate and experiment with models very quickly (www.lanner.com).
Witness employs fully interactive, visual approach to modelling and uses per-defined element types to represent manufacturing processes.

3.9.5 Conceptual Modelling

Conceptual modelling is certainly the most important aspect of the simulation modelling process (Law, 1991). Robinson (2004) states that, the model design impacts all aspects of the study, from data requirements, speed of the model development, validity of the model, the speed of experimentation and the confidence placed in the model results. He also highlighted that; a well-designed model significantly enhanced the possibility that a simulation study will meet its objectives with a set time.

Conceptual model is described by Zeigler (1976) in four terms: 1) the real systems – what the simulation model is to present; 2) experimental frame – limited set of circumstances under the real systems has been observed; 3) the base model – is capable to accounting for the complete behaviour of the real system; and 4) lumped model – the components of the system are lumped together and the interconnections are simplified. A more descriptive definition of a conceptual model by Robinson (2004) is:

"*The conceptual model is a non-software specific of the model that is to be developed describing the objectives, inputs, outputs, content, assumptions and specifications of the model".*

Key component of conceptual modes are:

- Objectives – the purpose of the model
- Inputs – elements of the model that can be altered, to effect the improvement (experimental factors)
- Outputs – reports the results from the simulation runs.
- Contents – the component that are represented in the model and their interconnections.
- Assumptions – made due to uncertainties of belief about real world being modelled.
- Simplifications – incorporated in the model to enable more rapid model development and use.

According to Robinson (2004), the content of the model should be described in terms of two dimensions:

- The scope of the model: the model boundary or the breadth of the real system that is to be included in the model.
- The level of detail: the detail to be included for each component in the model's scope.

3.9.6 Representing the Conceptual Model

The four common methods of representing the conceptual model are as follows:

- Component list
- Process flow diagram
- Logic flow diagram
- Activity cycle diagram
- Other includes UML notations, etc.

3.10 Chapter Summary

In this chapter, it has been shown that a great deal of work has over the years, been carried out in the area of factory and process design. The techniques and methodology available have been examined and analysed. The most fascination aspect of the finding is that, the earlier work carried out on this subject seems to have set precedent in the design of a factory and process selections with reference to pioneering work by Muther (1955) and several books by J. Burbidge.

The subject of virtual manufacturing has also been reviewed at length, and the literature available highlights where VM is applicable within the manufacturing environments and its benefits. Interestingly, the authors share similar views of the subject.

4 Research Methodology

In this chapter, details of the research design, research instruments, simulation method including the software used is discussed. Data analysis strategies and work program used in this project are well presented.

4.1 Research Design

This research project is both qualitative and interpretative. The researcher used research questions instead of hypothesis and the main objective of doing so was to seek answers to the questions during the research process. The research question was a key issue of concern that the researcher wanted to fully solve and interpret for better evaluation of the design concept for factory layout designs, and the rotor blade manufacturing.

4.2 Simulation Software Used

The researcher agreed with the supervisor and Rolls Royce management to the Witness simulation package. The aim is to make it easy for Rolls-Royce team to interpret any findings and recommendations using Excel-Witness configuration.

4.3 Data Collection and Handling

There were two methods employed in data collection. The first method involves collecting data from libraries, textbooks, journals and Internet websites. The second method involves gathering data from Rolls Royce, which in turn is used to generate simulation/simulated results. These data generated during simulation will be used in chapter six and for results analysis in chapter seven.

4.4 Research Instruments

This being a research project that is very sensitive, care is taken during data and information collection in order to safeguard the interest of Rolls Royce. Therefore, all the informal interviews with Process and Industrial Engineer were carefully formulated in order to come out with the results as discussed in Chapter seven. The research instruments were: -

- Library search
- Internet website
- Document analysis of work process
- Information interviews and discussion

4.5 Data Analysis

In order for the researcher to come up with a good evaluation of the project three models will be designed and simulated. Data generated will help to build a family of Witness-Excel simulation for three types of manufacturing layouts (functional, cellular and hybrid configuration) and analysed for Rolls Royce. The data will be collected and presented in logical manner/order in Chapter six. These data will help in arriving at any conclusions.

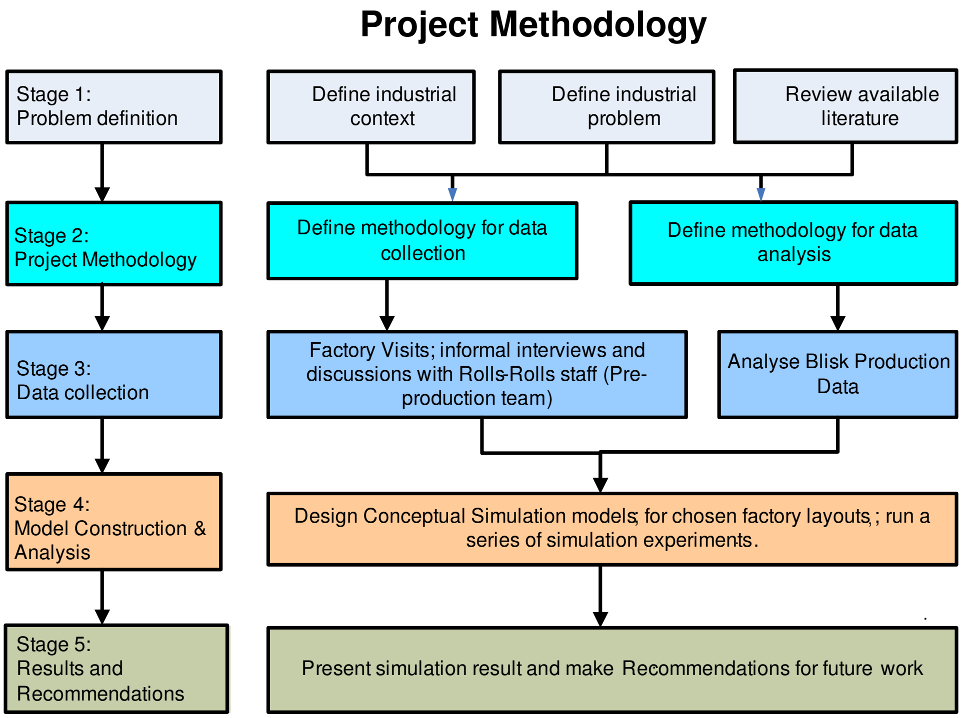


Figure 4-1: Project Methodology

5 An Overview of the Current Rolls-Royce Manufacturing Systems (AS-IS)

5.1 Introduction

This chapter will introduce and describe the manufacturing process and facilities for integrally bladed rotor (Generic-blisk), as well providing the general overview of Rolls-Royce manufacturing systems. Later on in the chapter it will discuss the manufacturing and business performance measurements, manufacturing planning and control, and finally a brief outline of the current shop-flow layout and workflow for the pre-production facility.

Manufacturing is an organised activity, which is committed to the transformation of raw material into finished goods for sale, or intermediate processes involving the production or finishing of semi-manufacture. The purpose of the overview is to enable the reader to understand the weaknesses of the current manufacturing system and identify the inefficiencies of the system and potential area of improvements. This will further expose and/or justify the need of the thesis work. Whilst examining these issues, the reader is also informed at this stage that, Generic-blisk manufacturing is still in 'pre-production' stages, with many processes still under scrutiny and is likely to change. The current production lead-time is approximately nine month. Full production is projected to commence in three to four years time.

5.2 Integrally Bladed Rotors (IBRs)

According a report in Trends in Technological Innovation, (www.rand.org), "Integrally bladed rotors (IBRs), also called bladed disks, are one-piece units that make up the rotation of a fan or compressor stage of a jet engine. IRBs consist of several blades (airfoils) attached to rotor that holds the blades in position and is attached to the other compressor/fan rotors and shaft in the engine. An IRB can be manufactured as single part if the blades can be welded to the rotor during manufacturing. Currently, fan blades that are hollow for reduced weight are welded onto the rotor. IBRs are quickly becoming the norm in newly developed fans and compressors”

5.3 Generic-blisk (Bladed-Disk) Manufacturing

Rolls-Royce key strength is its continuing investment in new *technology capabilities and infrastructure*. Its corporate strategy has been developed to ensure that the Group continue to grow as well as maintain their presence in all the four business sectors. The Generic-blisk project brought a new challenge to the Group, and one of this has been the development of the Generic-blisk rotor to replace the conventional assembly of blades and discs, with a single integral component. Figure 5-1 below illustrates a comparison of traditional bladed rotor with Generic-blisk rotor.

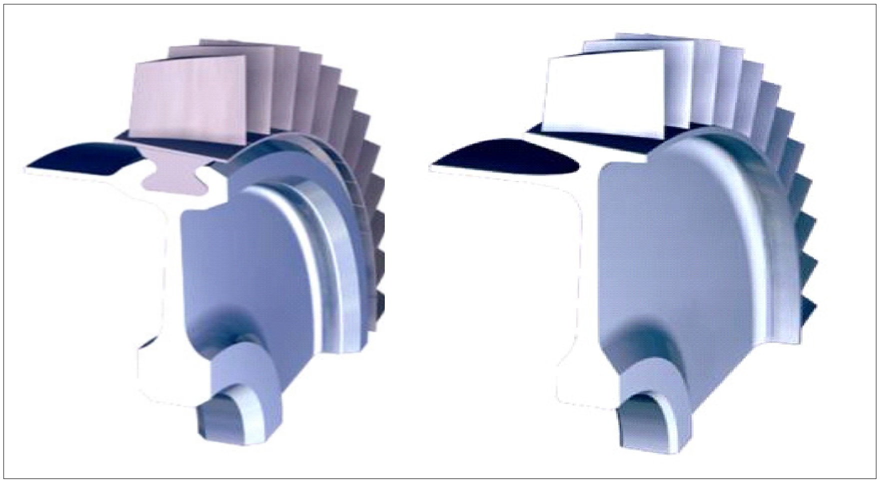


Figure 5-1: Comparison of Traditional Bladed Rotor with Integral Bladed Disk (source: Rolls-Royce Plc, 2007)

Unlike traditional bladed rotor where the blades are slotted in the disc, the Generic-blisk technology involves welding the blades on the disk and several machining and other processes are performed to achieve the design. The technology offers many advantages over the traditional bladed rotors, due to the weight reduction and other design aspects; however, they are complex components thus, necessitates high level of skills and advance manufacturing methods.

Generic-blisk technology coupled with the Rolls-Royce overall industrial advancement has put the Group at the forefront of the bladed rotor manufacture. This development is currently supported by two major Compression systems facilities in Annesley (UK) and Oberursel (Germany). Like other Rolls-Royce products, Generic-blisk is manufactured for both civil and military engines, and manufacturing capability ranges form small machined from solid stages to large hollow bladed fans.

5.3.1 SF Generic-blisk Manufacture

The manufacture of Generic-blisk comprises of five parts divided into two categories as small and large blisk. The development of the Generic-blisk has been a significant factor in terms of investment and technological challenges. The Group stands to gain significant reward in terms of sales, spares, services support as well as funding for product design.

5.4 Generic-blisk Production and Facilities

Rolls-Rolls are currently developing capabilities to meet the challenges that Generic-blisk manufacture presents. Barnoldswick and Annesley facilities are currently used for product development, at a very small scale. The above sites do not have the capacity to meet the projected volume. Part of thesis project will form a basis for recommendation on facility requirements.

Generally, due to its complexity as mentioned above, the production of the Generic-blisk involves a many intricate operation performed a range of machines and equipment. A brief study and analysis of the volume stream mapping and flow-chart shows a lot of replication of operation throughout the manufacturing route, totalling 108 processes. Figure 5-3 illustrates the stages and the frequency of part travel within the process. The descriptions of the process have been changed for confidentiality.

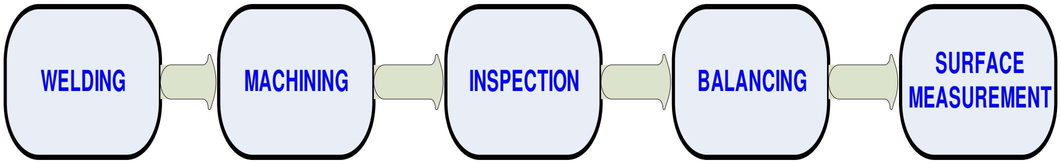


Figure 5-2: Generic-blisk Manufacturing Stages

5.4.1 Welding Process

Linear Friction welding (LFW) involves solid-state joining of materials through the relative motion of two components under compressive forces. During processing, frictional heat and deformation strain in generated and results in continued plasticization of the interfacial region between the work pieces and displacement of plastically deformed material toward the weld edges (Wanjara and Jahazi, 2005).

LFW is mainly used in the aircraft engine manufacturing, where the high value-added cost of the components justifies the capital cost of the joining equipment. Linear Friction welding is used to join a variety of materials including titanium, aluminium, steel, etc. LFW is the most important aspect of the Generic-blisk manufacture. The process also require long changeover (setups), estimated currently as around two hours per part number.

5.4.2 Machining and other Operations

To carry out analysis on machines the researcher decided to study the frequency of operation on each machine; the number of times the component visits the machines. From the VSM and Flow chart analysis, the result indicates that, the process route of bliks components have numerous operations ranging from short to very long production cycles. This is due to the intricate operations and complexity of the design. Figure 5-3 captures the frequency of operation.

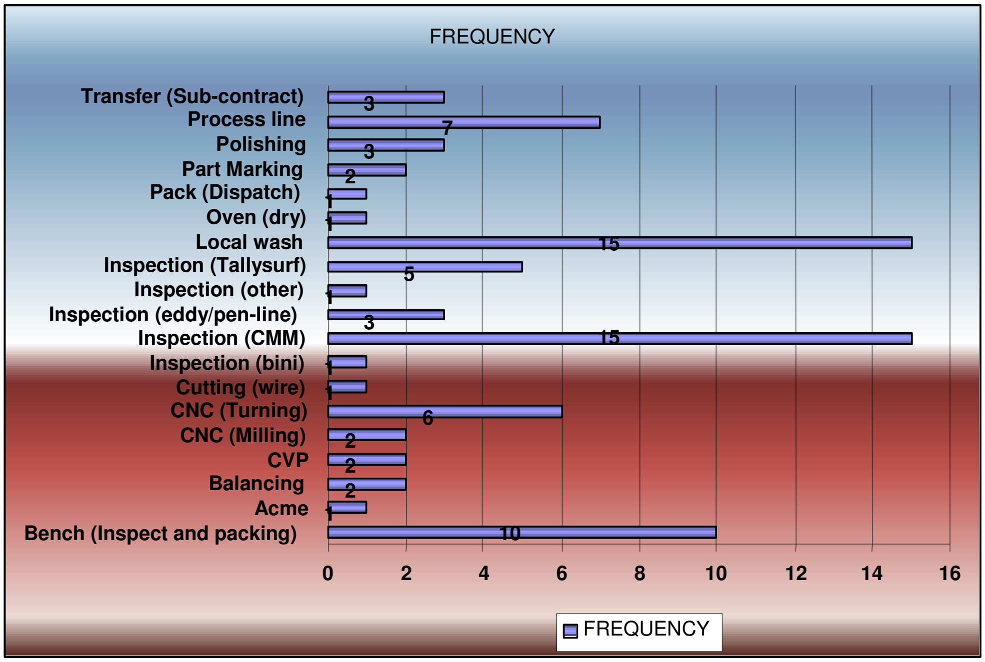


Figure 5-3: Frequency of Machine Process Cycle (source: Rolls-Royce plc, 2007)

5.4.3 Floor To Floor (Cycle) Time

Rolls Royce has a unique method of measuring work or machining cycle; described as floor-to-floor time. This measure incorporates and takes into account the following: 1) touch time; 2) process delay; 3) machine cycle; and 4) load and unload. Figure 5-4 below illustrates typical production work content, which from the floor-to-floor times.

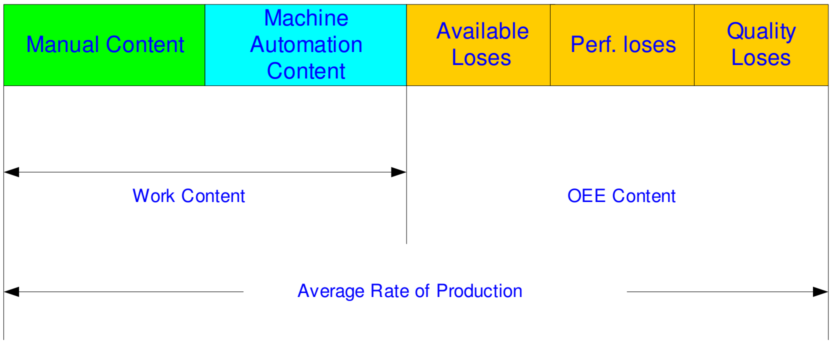


Figure 5-4: Work Content (source: Rolls-Royce, 2007)

The problem with this method, when carrying out simulation studies, it does not provide accurate time for analysis, for example in evaluating machine utilization and production capacity, the exact measure of performances may not be obtained.

5.5 Capacity Planning

Capacity is the ability to hold, receive, store and accommodate; the amount of output that the system is capable of achieving at a particular time. In management context, it is the amount of resource inputs available relative to output requirements at a given period. Company long-term competitive strategy must incorporate a capacity target that best suit its competitive strategy. Addressing the capacity issue at an early stage in production is viewed as a mean to solving long-term problems. In the design of a "focused factory" determining capacity requirements must address the demand for product and plan capabilities indicating how and when to increase additional capacity. Capacity forecasting techniques are recommended to determine the level of; sales, labour and equipment requirements to meet the product life forecast.

Correct balance between capacity and demand can be beneficial to the company; generating profits and satisfied customers, whereas getting the balance 'wrong' can be detrimental to company.

5.5.1 Capacity Planning Decision

Capacity planning decision is a subject that requires careful analysis because it affects several different aspects business operations and performances, as indicated below by Slack et al (1998):

a) ***Costs*** will be affected by the balance-of between capacity and demand (or output level if that is different); capacity level in excess demand could mean under-utilization of capacity and therefore high unit cost.

b) ***Revenue*** *this* will also be affected by the balance between capacity and demand.

c) ***Working capital*** will be affected if an operation decides to build up finished goods inventory prior to demand.

d) ***Quality*** of goods or services might be affected by a capacity plan, which involved large fluctuations in capacity levels, by hiring temporary workers for example.

5.6 Performance Measurement

Performance measurement can be defined as the process of quantifying the efficiency and effectiveness of past actions. A performance measure can be defined as a parameter used to quantify the efficiency and/ or effectiveness of past actions (Neely *et al*, 2002).

5.6.1 Process Performance Measurements

Process performance measurement (PPM) is concern with collecting and analysing data associated with predefined performance goal and standard. It is usually associated with prevention and detection aimed at achieving a conformance of the process requirements or expectations. The conceptual simulation designs will require a number of performance and conformance measure to be performed to predict the behaviour of the models. The following are PPM that can be carried out:

1) ***Process capacity*** – the capacity of the process; maximum output rate, which is measured by dividing unit produced by unit output.
2) ***Capacity utilisation*** – percentage capacity being utilised.
3) ***Throughput (flow rate)*** – average rate of flow for a given point.
4) ***Lead-time (flow time)*** – the average rate that a unit requires s flow through the process form entry to exit point.
5) ***Cycle time*** (or floor-to-floor time) – time between successive units, as they are output from the process.
6) ***Idle time*** – time when no activity is being performed, e.g., part waiting to arrive at station. This can equate for both machine and man.
7) ***Setup time*** – the time required to prepare the equipment to perform and activity; change in batch sizes or part family type.

Process improvements are carried out to achieve the following objectives:

- Cost
- Quality
- Flexibility
- Speed

Harrington, (1991) recommends the following methods for process improvement:

- To reduce WIP inventory – reduction in lead-time.
- Invest in additional resources to increase capacity of the bottleneck.
- Improve the efficiency of the bottleneck activity, leading to increase capacity.
- Redistribute work away from the bottleneck resources, if possible, leading to increased process capability.
- Increase availability of the bottleneck resources, for example, by adding another shift, etc, leading to increased process capabilities.
- Limit or reduce non value-added activities, leading to reduction in lead-time and cost. Non value-added activity includes, transport, re-work waiting, tooling, setups, inspections, etc.
- Redesign the product for better manufacturability – this can improve several or all process performance measures.
- Outsourcing some of the activity can create flexibility within the process.

The above process measurement will undoubtedly yield a significant improvement in the process, however, like any investment there is cost associated with it. Therefore, it is highly recommended that a cost comparison or cost benefit analysis be carried out for the project.

5.7 Manufacturing Planning and Control (MPC)

The essential task of the MPC systems is the coordination of material flows in the manufacturing systems; it helps to ensure a good management of manufacturing operations. Everything is push into the systems with this method. The major tasks for MPC are as follows:

- Business planning.
- Master production scheduling.
- Requirement planning.
- Factory coordination.
- Cell management.

Generally, the MPC systems, according to (Missbauer, 2002), the MPC consist of two levels:

  - Planning and control of material flow through the entire logistic chain, including capacity planning, at an appropriate level of aggregation.
  - Detail planning and schedule of material flow within the production units, usually performed at the shop flow level and for each production unit separately.

Rolls Royce currently employs SAP systems across all their functions. For the Generic-blisk pre-production it is used for launching product into the system. The ‘push’ manufacturing method is used at Rolls Royce.

5.8 Shop Flow Layout and Workflow

The key to achieving maximum efficiency required output and return on investment rest mainly on the shop flow layout and workflow, in respect to the design of the manufacturing systems in place. Currently, the pre-production facility has equipment grouped by similarities and functions. Job shop or functional configurations has notable advantages including higher flexibility, maximum utilisation of machinery and equipment, flexibility of arrangement, etc. Disadvantages include complexity of material flow, workers specialisation. Indeed the functional or job shop configuration causes unnecessary long travel distance between the processes.

Generic-blisk manufacturing itself has very complex operations and long cycles, with many repetitions in the process. Functional layout necessitates unwarranted WIP and long lead-times due to long queuing and transit time within the factory. The conceptual simulation design, however will take a look into all the available layout design methods; analyse and presents findings, which is the main objective for this thesis project.

5.9 Chapter Summary

This chapter presented an overview of the manufacturing systems, especially in the bladed rotor manufacturing; it examined the Rolls-Royce MPC systems, the thinking behind process routing and predominance measurements, and shop floor design and process flow. Moreover, it was to guide the reader and entails the technologies involve as well as the level of management science required to achieve the implementation.

6 The Development of the Simulation Models

6.1 Introduction

This chapter describes the various steps taken in the construction of the finished conceptual design simulation model. The chapter highlights the level and logic behind the construction; data collection process and improvement will be identified. Figure 6.1 is used to illustrate the process of conceptual modelling.

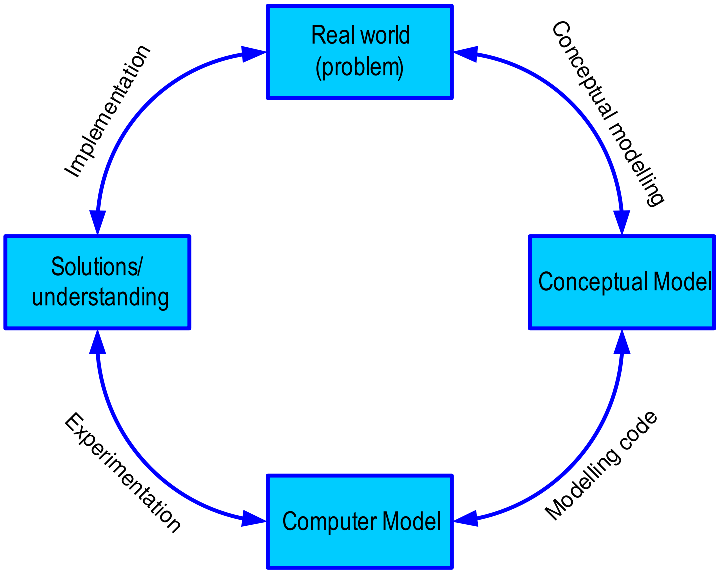


Figure 6-1: Simulation Stages: Key Stages and Progress (Robinson, 2004)

6.2 Data Collected

To begin the simulation modelling activity the right type of data is required. For this thesis, a considerable amount of data was available from the Pre-Production team. These included, process route and process times, flow chart, generic Linear Friction Welding (LFW) spreadsheet containing production information, and generic value stream map (VSM). The LFW data especially helped to revise the VSM and flow chart; providing updated time and process routing for the operations.

The data collected were analysed, cross-checked with Rolls-Royce management before using them in the simulation studies. Changes in the data or improvement in the process times, routings, etc, which occurred during simulation study, for example, improvement in the LFW routing by Rolls-Royce production team, which lead to reduction in process (welding) times, were passed on to the researcher and hence incorporated in the studies.

6.3 The Model Design

The model design and study focused on the following three notable factory layout methodologies:

1. Functional layout,
2. Cellular layout,
3. Hybrid configuration (combination of cellular and functional).

The *functional* layout design captured the current pre-production setups. The *cellular* layout incorporated medium to large cells; creating a single-direction flow. The *hybrid configuration* is formulated after analysing the first two layouts, thus it used to utilise the machines, space, production time, etc.

6.3.1 Description of the Route

For simplicity of the simulation study, a part is released as a single entity into the system (batch size of one); it will enter and leave the systems as a single piece. The sequence of operation is very simply; all the parts follow the same succession and processed on matching machines, except for the LFW, where the operation is divided into two categories comprising of small and large Generic-blisk. It is also the only operation that requires setup, due to its complexity and variations in the Floor-to-Floor time.

6.3.2 Construction and Logic

The model construction was performed in simplified steps recommended and practice by Rolls-Royce team. The Witness- Excel configuration allows a non-Witness user to generate simulated data and hence perform simulation analysis successfully. Below is the logic of method:

- *ReadFromExcel:* reads data, usually inputs (cycle times, number of machines), directly into Witness variables.

- *WriteToExcel*: writes data, usually outputs (utilization, throughput times), directly to Excel sheet.
- The Excel workbook should be in the same folder as the model.

This method speeds up the transfer significantly when transferring large amount of data (Tjahjono, 2006).

6.3.3 Routing Element (Part Routing)

The routing element is a useful facility that can allow for different types of parts to pass through an element, without engaging in writing complex rules. This allows the analyst to set the output rules of elements on the route to 'PUSH to Route'. This is particularly useful if different types of parts pass through a machine and they all have different setup times or cycle times. Parts with routes have two special attributes that store the setup and cycle times of parts on each stage of the route: R_SETUP and R_CYCLE in the appropriate machine's setup or cycle time field. Again, it doesn't warrant entering complex logic to work out the setup or cycle times of different parts passing through the machine. Each machine is assigned a *buffer*, which serves party as storage and routing buffer. Parts are pulled form buffers, processed and pushed to route and subsequently to the next buffer/operation. Figure 6-2 below is a Witness screen illustrating the routing element.

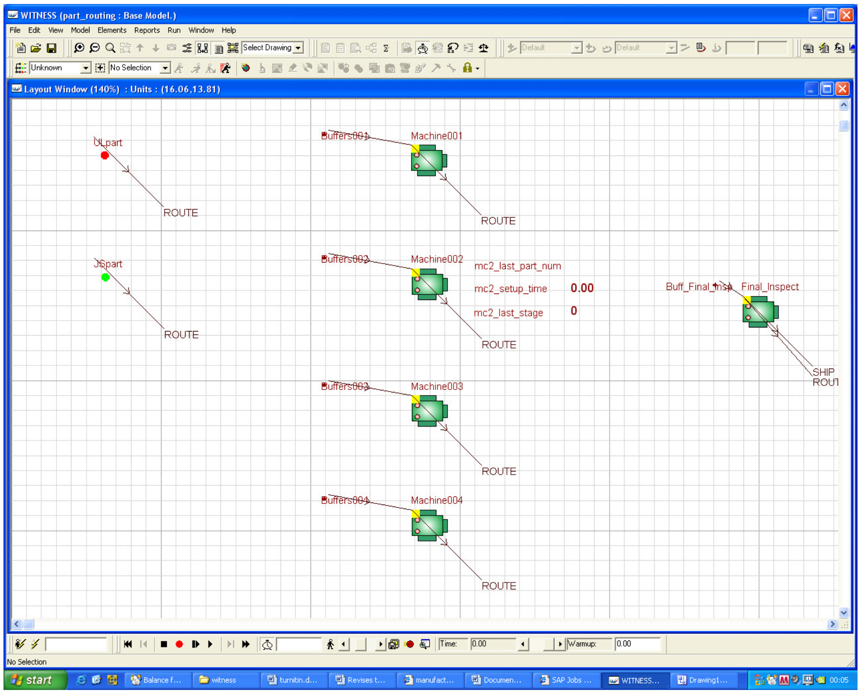


Figure 6-2: Routing Element

6.3.4 Part Launching

Part launching will determine the performance and the result of the simulation. Too many parts in the system would create a bottleneck, which may lead to unwarranted increase of capacity. Too little also means machine under-utilization. To arrive at a feasible launch period, a succession of analyses is carried out, methods are presented below:

Table 6-1: Generic-blisk Production detail

Production Detail	
Annual required volume	Confidential
Annual load inflation	20%
Batch size	1
Loading time (hours)	120
Annual production time (hours)	Confidential
Takt time (hours)	Confidential
Scrap level	5%

Table 6-2: Launch Times for Generic-blisk

Parts	Ratio	Minimum Vol.+5%	Target Vol.+5%+20%
2*L-Generic-blisk (large)	3:1	6183.9 min	5153.2 min
F-Generic-blisks1 (large)	1:1	2073.9 min	1728.2 min
2*F-Generic-blisks2 (small)	1:1	2074.9 min	1728.2 min

6.4 The Base Model

The basis of a good model is in its design; and the rule of thumb is keeping it simple. A model with too many inputs will lead to its complexity and hence may not achieve its objectives. Thankfully, the process route of Generic-blisk production is not complicated as it consists of only a single flow path for all the parts. As cited in chapter 5.7, the models built adhere to RR MPC principle.

The models are designed to produce the projected volume (*confidential*) per annum, including additional 5% for scrap, and 20% capacity headroom. The capacity cushion is designed into the model to cope with any eventuality in the production, including non-conformance, or a sharp increase in demand. A capacity cushion also helps the factory with the growth of the production. The design also entails that the factory will achieve the current targeted volume at 80% efficiency.

6.4.1 Model logic

The logic of the model has been developed to allow for ease of modification; adapting to new requirements by simply manipulating the Excel data sheet. This assumption forms the basis of this simulation project. It was decided and defined in accordance with the model objectives, which also helped in the information and data gathering.

Subsequently the following logic were adopted and used throughout the study:

- Parts are launched into the system at a given interval at a ratio of 1:1:3.

- FIFO rule for the parts, where the parts have to revisits an operation.
- The parts (component) are routed and through excel configurations; are assigned to respective work-stations/machines.
- Lead-time, Work-in-process, throughput and machines are the parameters for analysis.

The decision for the logic and the subsequent assumption in section 6.4.3 below, were arrived at in regards to the current state of Generic-blisk production. Most operations are still subject to changes therefore the study was limited.

6.4.2 Elements of the Models

A good model must entail all the list of elements their functions, the logic and their characteristics. Witness uses the same combination of things to model the real-life operation. Each component of the model is called an element. Some elements represent physical things (such as parts, fluids, pipes, vehicles, machines, conveyors and labour), some represent intangible things (such as shifts, attributes, variables, distributions and files) and some represent graphs that the analyst can include in the model's display (timeseries, histograms and pie charts) (Lanner, 2007).

6.4.3 The Model Assumption

The assumption made in the design stage of simulation modelling is to set the boundary of the experiment to steer the study in the right direction as well as adhering to the requirements and scope of the project. For this thesis research, the following assumptions were made:

- Infinite labour and skills availability.
- Factory will run three shift bases on 24 hours day, and operation 49.6 weeks per year.
- Machine utilization is limited at 80% capacity. If more then another machine is introduced.
- Non-conformances (breakdown, etc) are eliminated; in other words, a perfect model.

- CMM and subcontract buffers to have a 24-hour delay to account for cooling time and sub-contract operations, respectively.
- Simulation time is in minutes.

6.4.4 Running the Model

To run the model efficiently the following input must be considered:

A) Inter-Arrival times (launch time)
B) Warm-up period
C) Run time

- ***Inter-Arrival Times (IAT)***

In this simulation study, the IAT has been used to launch the parts into the system, which also function as the interval times between the parts, and generally controlling the flow of the system.

- ***Warm-Up Period***

Warm-up period are assigned to ensure that the model is in a realistic condition before any values can be recorded. Determining warm-up period varies according to the type of simulation built. The model built is termed as “non-terminating” simulation. This means that the initial transient has passed and the model output is in steady-state (Robinson 2004).

For this project, the warm-up period was determined visually; by selecting the steady state period on the timeseries, and assigned into the model. Because of the differences in the design layouts, the warm-up times varies across the three models.

- ***Runtime***

Experimental time or runtimes are decided in the in the assumptions and usually adhered to better result as a good practice. In this study the runtime will be for the given available production time of 49.6 weeks.

6.5 Chapter Summary

This chapter presented key stages for conceptual simulation design, captured the data collection, the model design and construction. It also discussed the process routing and logic and assumption arrived at for the simulation study, as well as the techniques employed in simulation designed provided the flexibility so that different scenarios can be easily executed. The launch time and other input parameters allows to researcher/analyst to use the simulation to find the optimal combination of several factors; change variables; re-run the model; examine the results and repeating the process until the desired outcome is achieved.

7 Results and Analysis

7.1 Introduction

This section will provide the result obtained in the study of the conceptual simulation design for three types of models as sited in Chapter 6.3. Various results will be presented here in numerous method and formats. The outcome of the experiments will be presented in stages; firstly, the results showing level of WIP, lead-time, and the associated capital cost, generated after running the models will be presented. The associated capital cost is based on the cost of equipments and the required for the installation.

7.2 The Results of the Simulation

The first set of results is for scenario one with a target output of 1,000 + 5%, with minimum capacity to meet that volume. This is presented in Table 7-1 below.

Table 7-1: Scenario 1 Results

	Functional Layout	Cellular Layout	Hybrid Layout
WIP (parts)	64.00	56.00	63.00
Lead-time (days)	25.00	22.00	25.00
Number of Machines/Operations	61	93	77
Capital Cost	£30M	£38M	£35M

The second set of results is for scenario two with a target output of 1000 + 5% + 20% with a minimum capacity to meet that volume. This is presented in Table 7-2 below.

Table 7-2: Scenario 2 Results

	Functional Layout	Cellular Layout	Hybrid Layout
WIP (parts)	77.80	67.00	62.00
Lead-time (days)	27.00	22.00	24.00
Number of Machines/Operations	61	93	77
Capital Cost	£30M	£38M	£35M

The third set is for scenario three with a target out of 1000 + 5% + 20% with a revised capacity to meet the volume. This is presented in Table 7-3 below.

Table 7-3: Scenario 3 Results

	Functional Layout	Cellular Layout	Hybrid Layout
WIP (parts)	64.00	55.00	62.00
Lead-time (days)	25.00	22.00	24.00
Number of Machines/Operations	69	100	81
Capital Cost	£34M	£44M	£38M

The bar chart Figure 7.1 below, illustrates the variation in performances for a minimum capacity to meet the volume. Figure 7-2 however, represent s the changes in the performance parameters as a result of an increase of 20% in the volume for the same scenario.

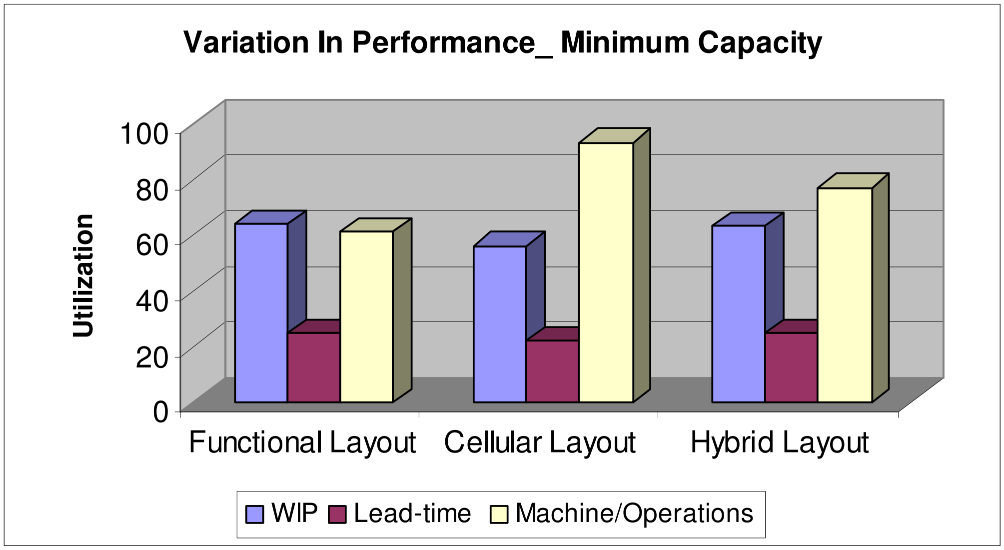


Figure 7-1: Comparisons of results

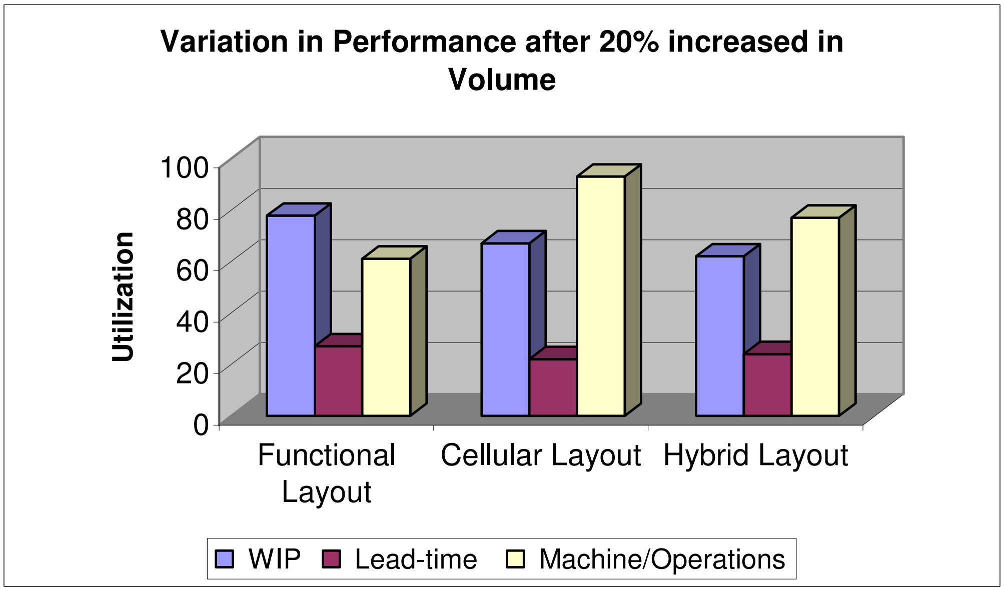


Figure 7-2: Comparisons of Results

The bar chart Figure 7-3 below, presents the changes in the performance parameters as a result of an increase of 20% in the volume with a revised capacity to match the volume. The subsequent bar chart Figure 7-4 is a cost comparison of capital equipment for the different manufacturing layout for scenario three.

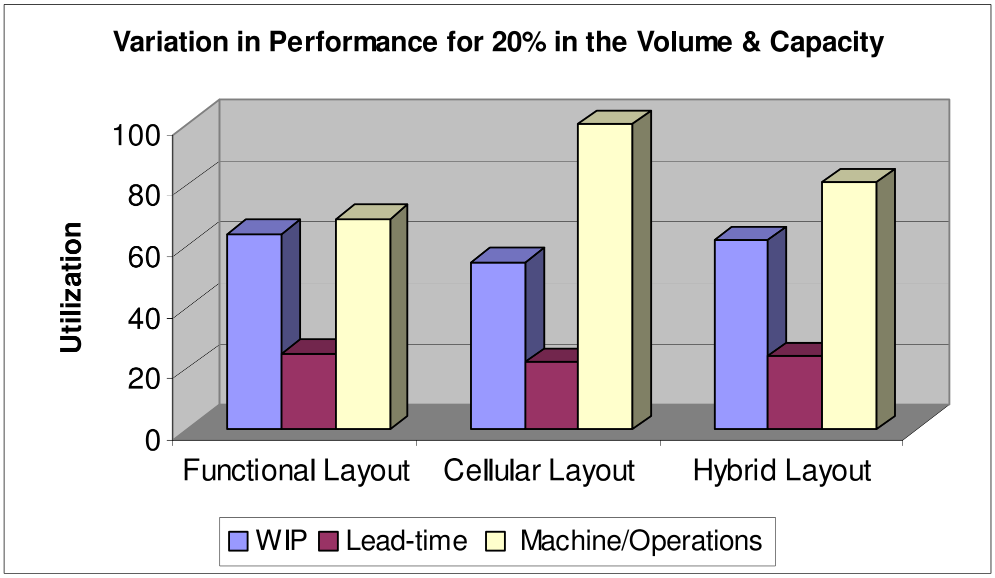


Figure 7-3: Comparisons of Results

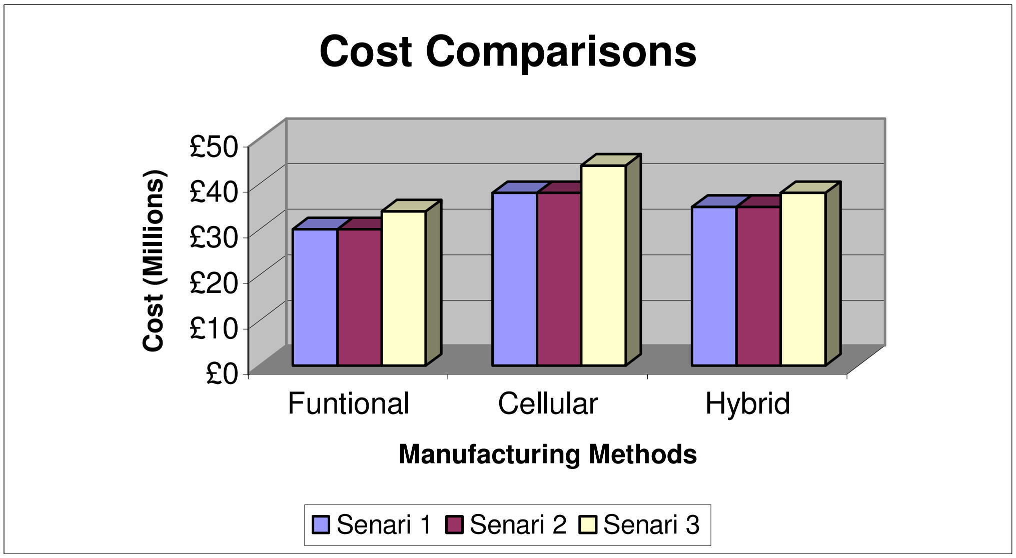


Figure 7-4: Capital Cost Comparisons for scenario three.

Table 7-4 below presents the distribution of the WIP, the mean, min and maximum values, for small and large small Generic-blisk for the different layouts designs.

Table 7-4: Result of the WIP Analysis

WIP	**Functional Layout**		**Cellular Layout**		**Hybrid Configuration**	
	Small	Large	Small	Large	Small	Large
Mean	29	35	32	35	28	34
Min	27	34	30	34	27	33
Max	30	36	33	36	29	35

Figure 7-5 to7-10 below, presents the frequency of the WIP; how the Min and Max values are distributed during this simulation studies. This is to aid in monitoring and determining the behaviour of the systems in terms of WIP.

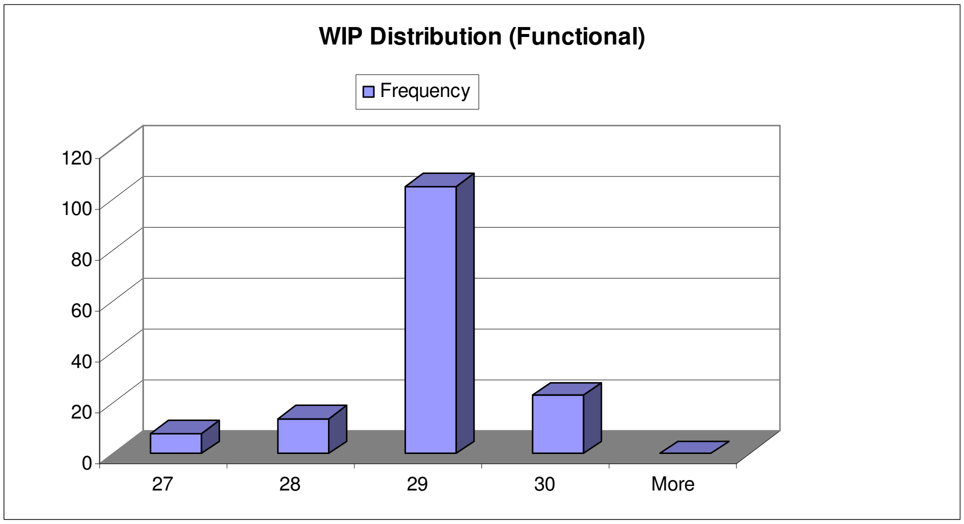


Figure 7-5: WIP Distribution (Functional) Small

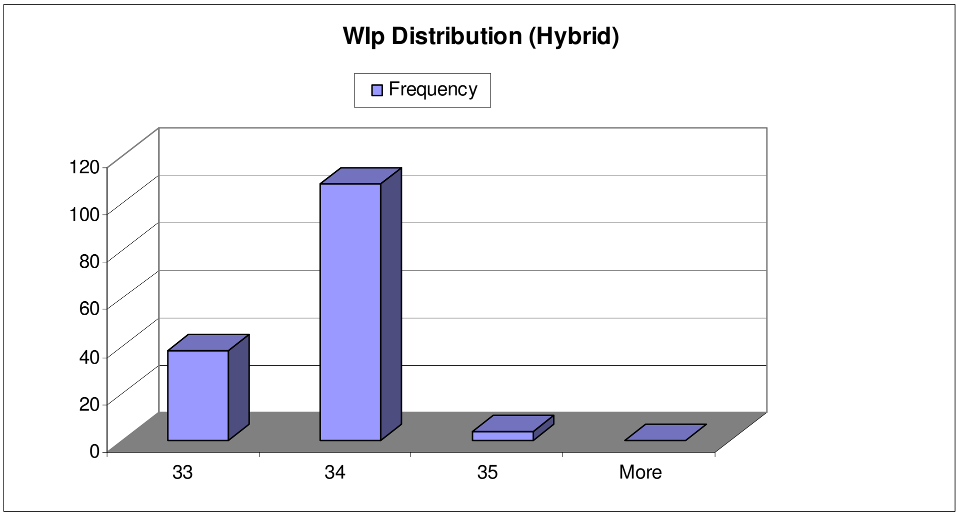


Figure 7-6: WIP Distribution (Functional) Large

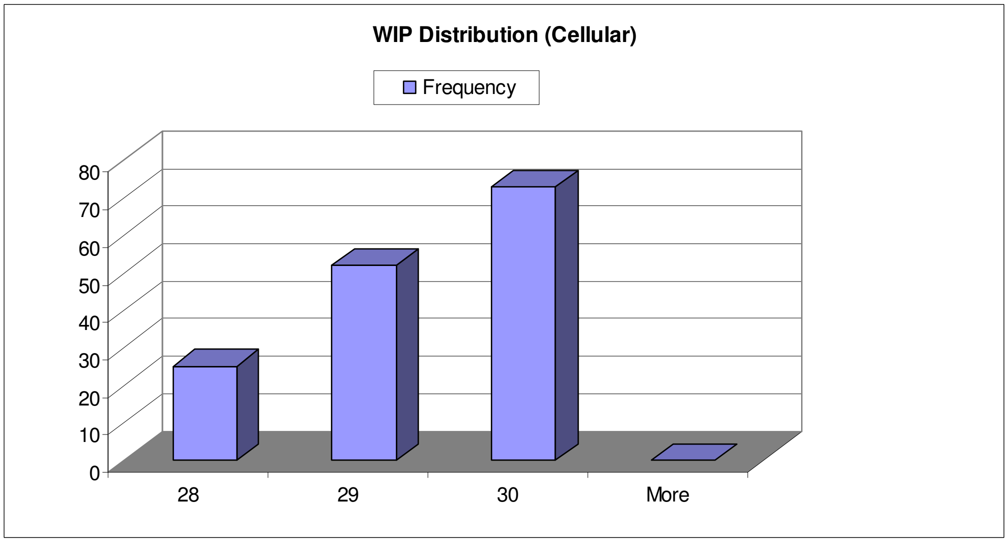


Figure 7-7: WIP Distribution (Cellular) Small

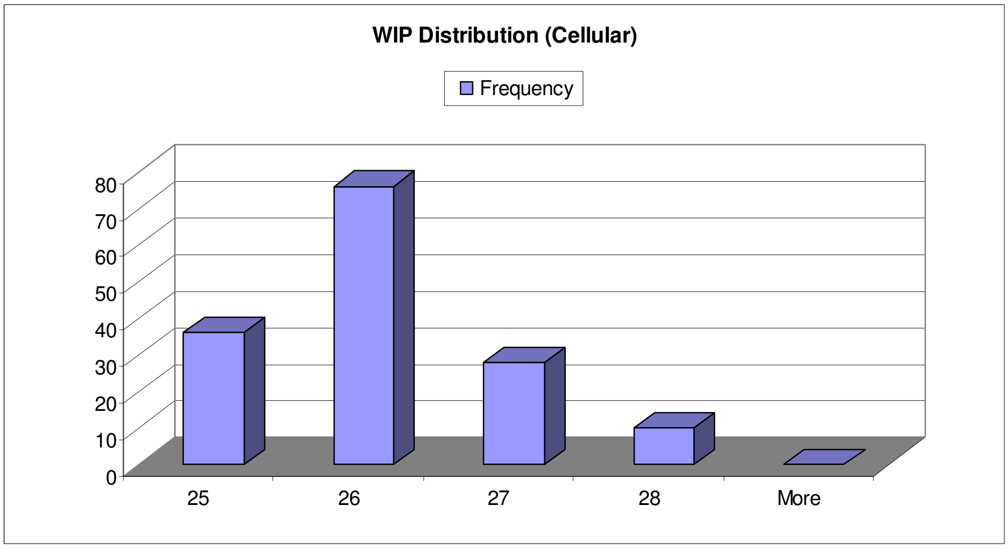


Figure 7-8: WIP Distribution (Cellular) Large

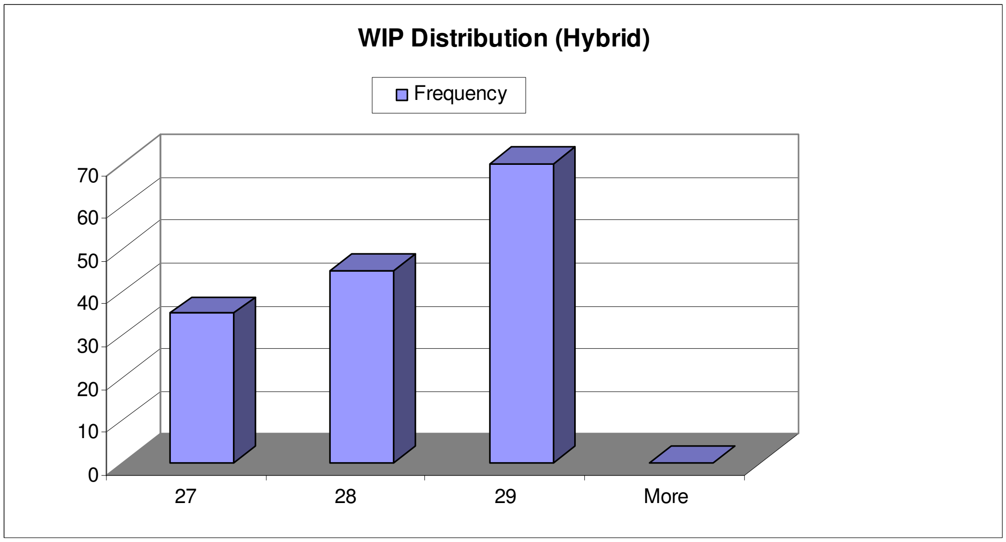


Figure 7-9: WIP Distribution (Hybrid) Small

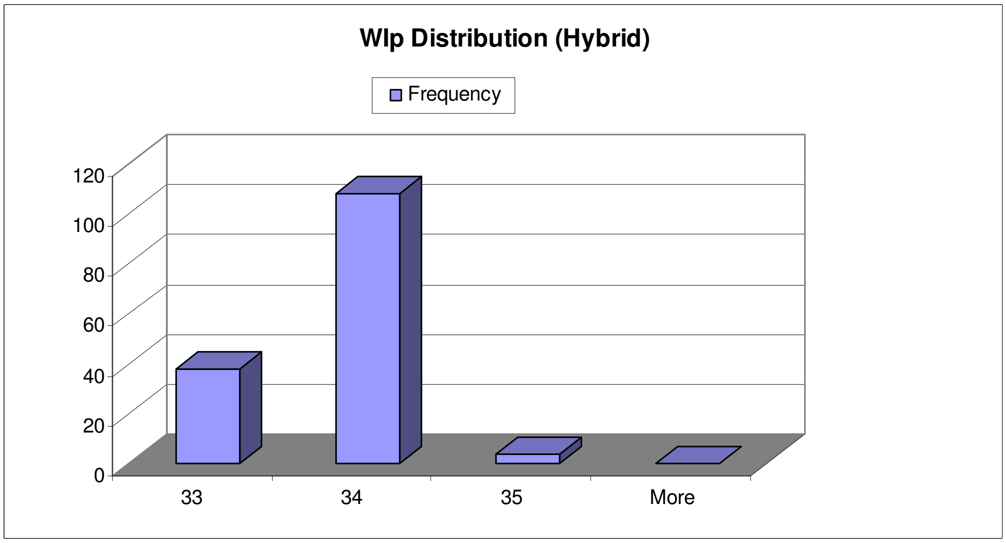


Figure 7-10: WIP Distribution (Hybrid) Large

Figure 7-11 to 7-13 presets the outcome of machine and operation utilization for scenario 1 and 2, for three layouts.

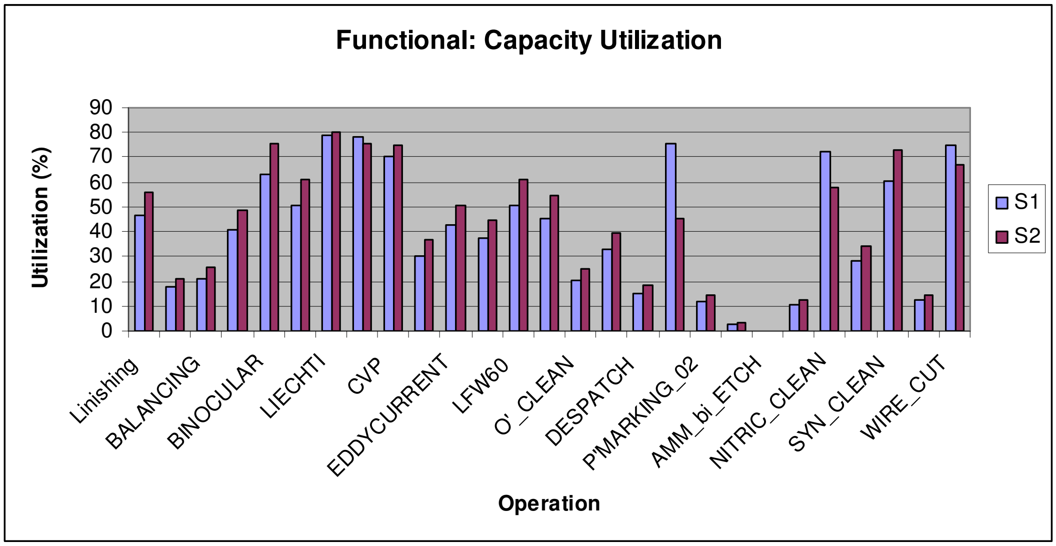


Figure 7-11: Performance Graph for Scenario 1&2 (Functional)

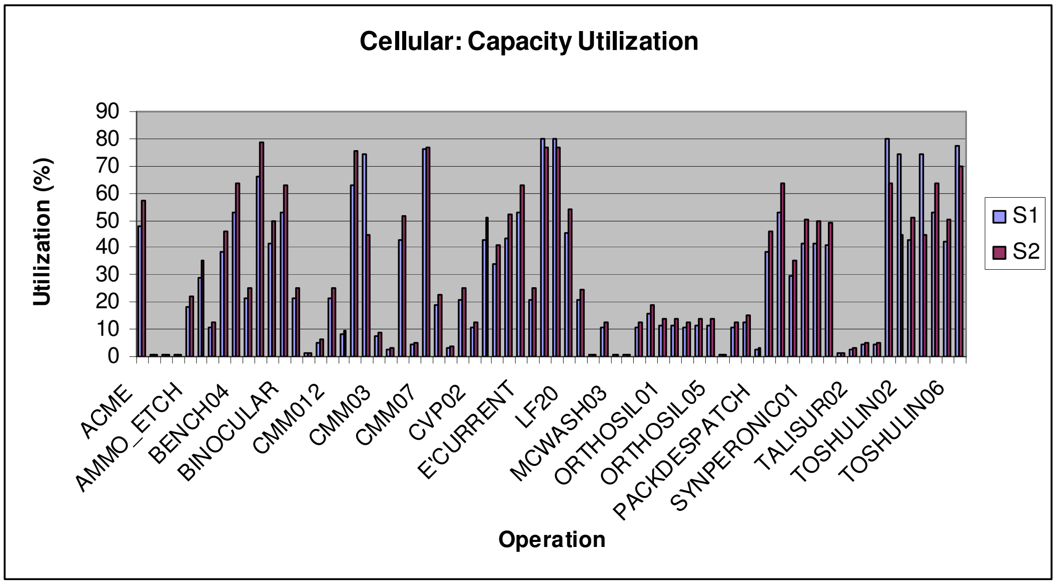


Figure 7-12: Performance Graph for Scenario 1&2 (Cellular)

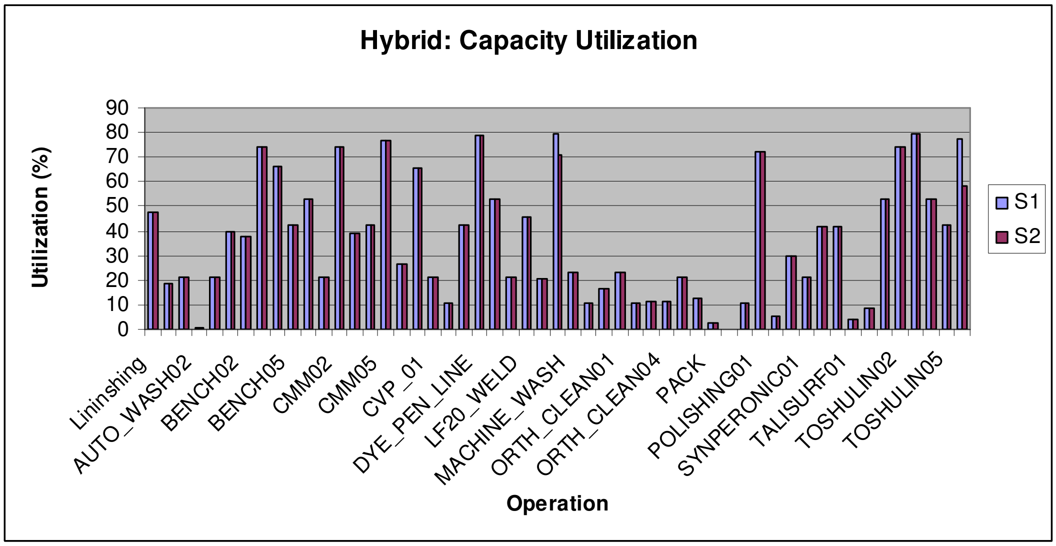


Figure 7-13: Performance Graph for Scenario 1&2 (Hybrid)

Figure 7-14 below illustrates and compares the level of machine performance or utilization for each operation on all the layouts.

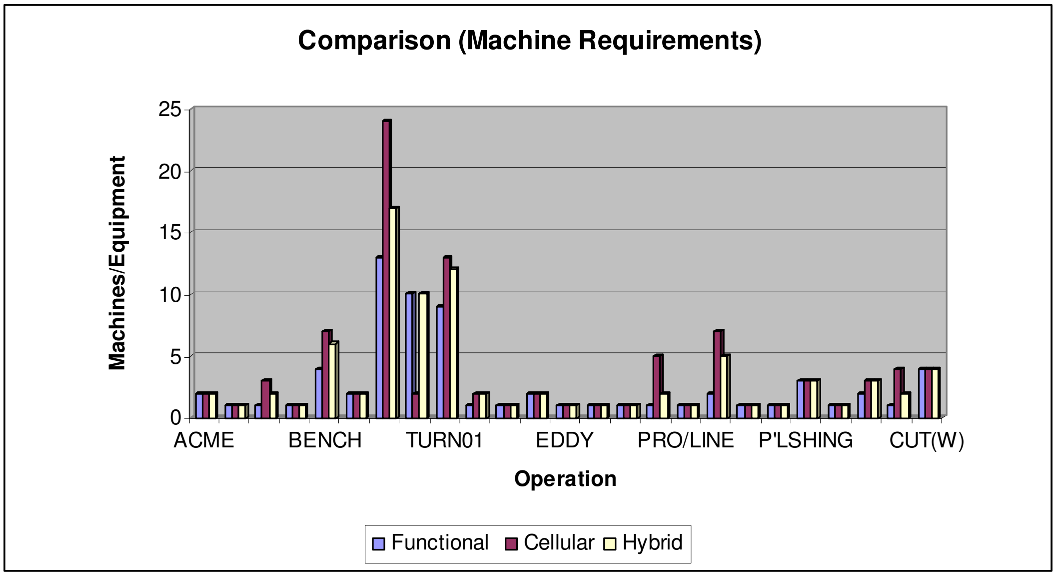


Figure 7-14: Comparison: Facility Utilization

7.3 Performance Analysis

This part of the thesis will provide explanation to the results as presented in section 7.2 above. The investigation is carried out on the functional, cellular and hybrid layouts in view of understanding the performance evaluation and providing a broader picture of the simulation study. To help in drawing a conclusive and subsequent recommendation for the selection of the layout, the following will be examined:

a) The effects of the changes in the number of machine tools in the layouts has a direct relationship between the number of machine tools and the percentage change in the factors and ratios in terms of expansions and utilization after the changes in layout design.
b) Factors associated with the arrangement of machines tools in cells, and other critical components like part movement and floor space.
c) Further considerations on where the greatest change occurs. Is it where machine require longer hours or short operations?
d) A determination of possible places of notable differences between the manufacturing methods.

To get a clear basis for the analysis of the model and hence arrive at a realistic conclusion, the following observations were carried out on layouts:

- Behaviour of the WIP under different conditions.
- Lead –time was monitored for different conditions.
- Changes in throughputs in relation to capacity and volume changes.
- Capacity utilization was examined
- The effect of changes in the number of machines in relations to machine utilization and efficiency.

Interestingly, the cellular layout offered favourable results performance-wise, but overall, it is a very expensive method. Many machines and processes were under-utilised and had very large works cells requiring much space. Moreover the cost of space is estimated at £1,200 per square metre. The functional layout however offered favourable outcomes in terms of cost. This however, much as the option is favourable, there are many disadvantages associated with the method, for example the number of times component travel back-and-forth within the factory, tracking component, lead-time and WIP. However, the overall performance for hybrid was much better with stable WIP and Lead-time under different conditions, the design also offered better machine capacity utilization than cellular Layout.

7.3.1 Analysis for Scenario 1, 2 and 3

The simulation result for scenario 1 and 2 shows increase in both WIP and lead-time for all the three layout designs. Based on 80% capacity utilization, scenario 1 captured a typical factory setup with a minimal capacity targeting the required volume. Scenario 2 however, attempts to reflect reality of factory behaviour and expectation. Here the study tried to push the capacity beyond the limitations to test it if it can cope with this uncertainty. The changes resulted in an increase in the level of WIP, lead-time and some machines were over utilized. Although some machines performed beyond the 80% set level, the system did not fail, i.e., the capacity was not over utilised and no stoppages (simulation) was experienced, which it is an indication that, in the short run with the level of the capacity, the factory can cope under this condition. However, the main change was in the functional layout, which was due to its characteristics, where the machines are properly utilised. This signifies that in this circumstance the design is likely to fail the systems unlike in cellular or hybrid layouts as clearly presented in figure 7.2 and 7.3.

The outcome of scenario 3 is the revised capacity to suit the 20% inflationary target or the capacity cushion. This headroom is provided to deal with any uncertainties, which may occur within the factory, from temporary breakdown and any non-conformances that are associated with the factory operations. The capacity was adjusted to match the operational capacity exceeding 80% limit. Due to this, the cost of space and machine were also increased by 13%, 16% and 7%, for functional, cellular and hybrid layouts, respectively.

7.3.2 WIP Analysis

This analysis is performed on the WIP to study the variants and the distribution of the in the mean WIP since the flow times control variables require controlling the level of WIP in the factory. Figures 7-5 to 7-10 are presented to show the distribution of the WIP for 150 samples for all the three layouts. Generally, the frequency presents a typical results of a perfect systems, and in the case of this research, it is because of the lack of the non-conformity in the model. In a normal factory environment, the frequency of the distribution will produce different results.

7.4 Hypothesis Testing

Hypothesis testing was carried on the hybrid modelling, based on results of scenario 3, to test the robustness of the model. Figure 7-14 above shows significant improvement in the performance of the model, with increased capacity utilization. There was also a slight change in the level of WIP and lead-time but not overly affected with an increase of 3% (64 to 66) and 8.3% and 8.3% respectively. The main changes occurred in the number of machines, from 83 to 60, machines/operation.

7.4.1 Capacity Utilization Analysis

The performance graphs presented in Figures 7.11 -7.13 show the differences in performance of machine due to changes in the volume for a scenario 1, 2 and 3. These give a clear basis for studying the performances of the machines and also in understanding the variations in cycle times for each operation. Here, the results are used to determine the extra capacity required the capacity cushion.

The results are also used to compare the performances of the layouts in terms of the overall capacity utilization, which contributes to the selection of the layout. Figure 7-13 illustrates the results of capacity utilization for the layouts, showing clearly that the hybrid model performing much better than cellular and function. In terms of works station and machines, the functional design gives a better result; however there are hidden factors that affect the whole functional types of operation. These factors are highlighted the literature review. The optimal level for the machine performance is 80% in the case where level is exceeded; a new machine or workstation must be introduced. This in effect will reduce the level of machine performance significantly. This assumption are usually dealt with and agreed in the initial stages of the factory design.

Figure 5-3 in Chapter 5 shows the frequency of part travel within the process, and this can help to understand the movements of parts in the system and the subsequent need to create flow. The system also uses the FIFO method, which means if part is revisiting the workstation it has to queue behind the one before. He the effect is greater on the functional layouts especially in operations with long cycles such as CMM, polishing and some machining processes.

7.4.2 Bottleneck Analysis

Generally, the CMM operation is the system's bottleneck, and thus for the systems throughput to improve, the bottleneck has to improve. Consequently machines were added to deal with the problem in this analysis. However main cause of the problem is due to 'cooling' delay. In the designs, the CMM buffers were assigned 24 hours cooling allowances. Before CMM operations, the component is washed, and this process causes a sharp increase in the component temperature and subsequent cooling is required. There are 15 CMM operations of which seven are sampled at 5% of the total production volume; full inspection is required for the other eight. This operation, which does not add value to the Generic-blisk manufacturing process account for over 50% increases in the operation cycle/lead-time.

7.5 Observations

Form the experimentation conducted, the researcher carried out the following observations, which were later used to arrive at a conclusion.

1. The results for scenario 1 and 2 showed that, when the capacity is stretched it could result to a short-term problem, especially in the functional type of manufacturing.
2. The changes in the volume after the 20% increased resulted in changes in lead-time and WIP, which was caused by too many parts in the process. From this, it has proven that excess capacity utilization leads to unwarranted level of WIP.
3. The researcher also observed due to limitation set in the assumptions; the only means of dealing with capacity overload is by introducing new machines into the system regardless of the level. This factors, with a proper MPC systems as a tool for controlling production may in effect be controlled elimination the need of deploying more machines as mean of dealing with the overload. All RR components are push into the systems as specified in chapter 5.7 above.

4. The literature review shows a trend towards hybrid configuration manufacturing due to its ability to utilise space and optimal capacity utilisation. This is also supported by the results outcome of this thesis work. The overall benefit however, will be realised when the whole factory design activity is completed, in the case of this project. Modelling transportation, non-conformances, material handling and movement within the shop-flow.

7.6 Chapter Summary

This chapter provided an in-depth analysis of the results generated in Chapter 6 of the simulation development. The results presented here clearly illustrated the dept of work carried out in this research thesis. The observation made has added to the analyst valuable knowledge of systems design and analysis. The Microsoft Excel to Witness configuration has provided the researcher with vital knowledge of simulation modelling and study.

8 Conclusion and Recommendations

8.1 Has The Project Achieved Its Objectives?

Defined were the following objectives:

1. To assess the current Generic-blisk factory facilities; utilisation of machines in the functional arrangement (job-shop).
2. To evaluate the current models for the future civil and military Generic-blisk factories using Witness simulation.
3. To evaluate various manufacturing and assembly methods including cellular, Job-shop, hybrid, designs to be considered.
4. Make recommendations as to how best to use Witness simulation for production planning to meet high volume demand.

The objectives of the project have been achieved; Rolls-Royce manufacturing systems have been examined; current Generic-blisk production facilities and Generic-blisk manufacturing methods were examined and presented in the reports. Furthermore, overview of the manufacturing systems was presented in chapter five.

The academic context of this project in chapter three, explored major areas and previous and current methods of factory design and facility layouts.

A series of conceptual simulation design were built, studies and findings presented. This in effect helps in presenting the investment justification of the project. The simulation results however, do not offer all the required information for a complete study of the factory design. It is however, played a key role in determining the number of equipment required and subsequent floor space required for the future factory capable of achieving high volume.

8.2 Lessons Learnt

The main lesson learnt during the study is the importance of simulation, the simulation of the manufacturing systems. Factory design and layout analysis, distinguishing between the various types of layout and the benefits offered.

As an instrument for the study, the researcher was able to gain a good knowledge of WITNESS simulation package; reducing the complexity of logic by linking the model to Excel spreadsheet subsequently reducing the time needed to perform a series of experiments.
General project management skills were gained as a result of working with a team of highly knowledgeable supervisors. This stems from managing time, to weekly meetings and meeting deadlines.

8.3 Limitations

To begin with, this thesis work forms part of a much bigger project; the conceptual simulation work aim only at forming the basis for further simulation and factory design work. Therefore, the researcher was restricted to perform a limited number of experiments on the models. WIP, lead-time, throughput, and machines performance, were analysed.

Numbers of equipments was based on the set level of performance; the machines were to perform to a maximum of 80% utilization. This in the absence of other factors that affects performances formed the basis of analysing and deciding on the number of equipment to be used. Factor analysis matrix was however, difficult to perform to aid in factory design selections due to lack of supporting evidence for decision making. The entire decision for selecting the layout design was theoretical and based on the advice from Rolls Royce. Hybrid layout, according many researchers and from the academic context of this reports, supported with the characteristic of the product, tends to offer the benefits that Cellular and functional layout does present.

The models built only take into consideration lead-time, WIP and throughput; of the system. The lead-time distribution is not typical of normal factory environment because it does not take into account non-conformance such as breakdowns, re-work, delays, etc. These factors would bring the system to a more realistic conclusion.

A Rolls-Royce method of measuring work/machine cycle gives a general figure of time, known as “Floor-to-Floor times”. When measuring machine performance, this time, which includes the machining, work content, are used, and may not be accurate. This is suitable in measuring manual operations and perhaps other performance evaluations.

8.4 Recommended Future Work

After carrying out analysis of the simulation models and the evaluation of Generic-blisk manufacturing; design and process routes the researcher as drawn a conclusion with the following recommendation for future work on the project:

1. Further work should include in-depth simulation/manufacturing operations, incorporating and analysing all the non-conformance characteristics of a typical factory. Breakdown matrix, re-work, delays, workers absentees, material handling and movement (major and minor), in addition to WIP, etc are the factors that would bring the system and study to a realistic conclusion.

2. Pilot and identify the impact of different work-shift, the effect on product as well as workers. This can be modelled from similarly pass RR projects. The focus can be on quality, productivity, absentees, etc.

3. Pilot and determine the exact work content time for cellular type of manufacturing, and well as establishing the exact operation time providing the best data for analysis, rather than employing estimates.

4. Investigate and invest in a different method of surface preparations/washing the components. Sharp increases in the component temperature due to washing operation require the parts to cool-down for a period of 24 hours, with an increase of 58% on lead-times.

5. Investigate and invest on CNC machinery that will incorporate milling and turning operations saving space, cost of machines, and possible labour.
6. Invest in suitable (flexible automated) material handling equipment; reducing human contact with the components, and possible reduction to the need and amount of cleaning operations.

7. Consider batching the welding operation, to reduce the setups and subsequently reduction in lead-time, WIP and etc.

8. Use performance matrix to draw a conclusive result for model selection. The criteria should be based on findings in the literature (chapter) of this project outlining and comparing the layout types.

9. The model does not give a complete result and solutions to the future factory design layout. Therefore, it is recommended that the later part of the project should include a complete study of factory physics, with the aid of FactoryCAD, FactoryFLOW and FactoryOPT for conclusive result. This technology and is sited in section 3.9 of the literature review.

10. It was identified during the study that RR uses a ‘Push’ systems across it manufacturing/operation spectrum, thus it would be difficult to determine an unbiased result for scheduling product in the market according the market requirements. It is recommended that the study should attempt to explore other method of MRP systems; which schedule material flow as sited in chapter 5.6.

11. Recommend a brief study of aggregate planning for ‘time-varying demand’ and sequence dependable setup times in relations to the welding operation, where changeovers are required.

12. Finally, the researcher recommends that the future factory should incorporate some element of a Kanban system into the current MPC due to the complexity and the lack of uniformity in the Generic-blisk manufacturing process.

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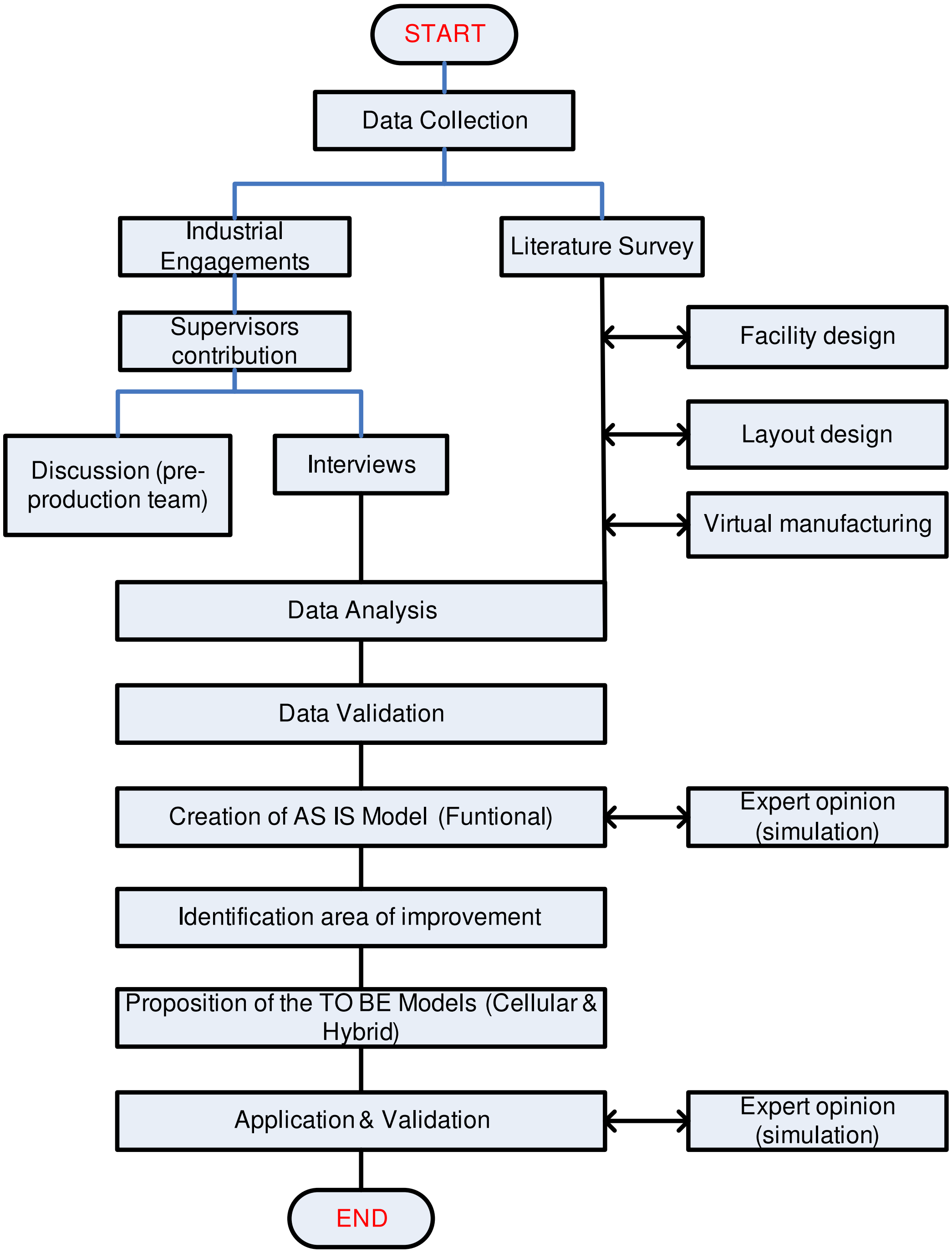
Appendix 1: Rolls-Royce Compression Facilities (UK)

Table 8-1: Rolls-Royce Compression Facilities (UK)

Derby	
Functions	Manufacture
Headquarters	HP and IP welded compressor assemblies
Design engineering	Shafts
Manufacturing engineering	Castings
Operations	
Logistics	
Quality	
Human Resources	
Inchnnan -Near Glasgow	
Functions	Manufacturers
Manufacturing engineering	Compressor blade and vanes
Operations	Seals
Logistics	Shrouds
Quality	
Barnoldswick - Lancashire	
Functions	Manufacturers
Manufacturing engineering	Wide Chord Fan Blades
Operations	Static Compressor Components
Logistics	
Quality	
Southern sites (Including Annesley, Hucknall and Ansty)	
Functions	Manufacturers
Manufacturing engineering	Annesley – Nottinghamshire
Operations	Generic-blisk
Logistics	Inertia Welding of Compressor Drums
Quality	***Hucknall – Nottinghamshire*** Outlet Guide Vanes (OGV) Generic-blisk – GENERIC-GENERIC-BLISK Pre-production ***Ansty – near Coventry*** Fan Casting

APPENDIX B: SIMULATION - RESEARCH STRUCTURE



APPENDIX C: TAXONOMY OF CELL FORMATION TECHNIQUES

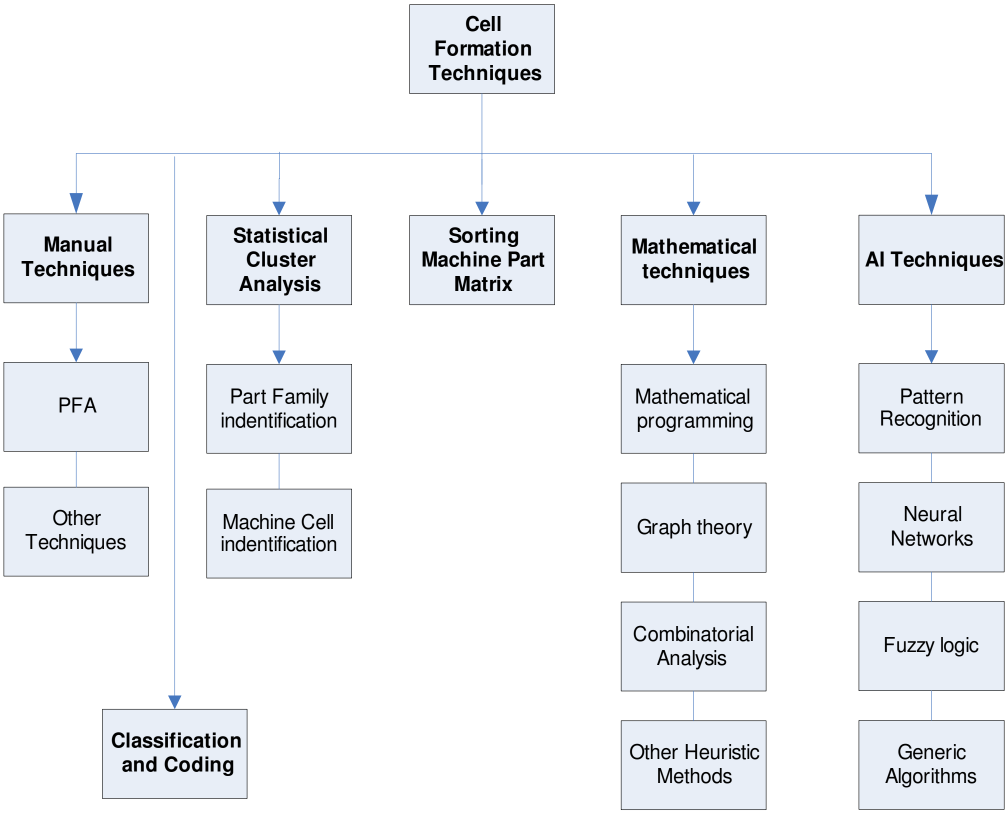


Figure X. Taxonomy of cell fromation techniques. Source: Suresh and Kay, (1998)

APPENDIX D: PROPOSED FACTORY (HYBRID) LAYOUT