Palmer, John (2011) Improving the management of inventory in the Rolls-Royce Energy Aftermarket Business. [Dissertation (University of Nottingham only)] (Unpublished)

University of Nottingham

Improving the Management of Inventory in the Rolls-Royce Energy Aftermarket Business

John Palmer

MSc

DISSERTATION (N14R14)
Executive MSc in Global Supply Chain Management

IMPROVING THE MANAGEMENT OF INVENTORY IN THE ROLLS-ROYCE ENERGY AFTERMARKET BUSINESS

by

John Palmer

2011

A Project presented in part consideration for the degree of Executive Master of Science

Note on Proprietary Information
In the interest of protecting Rolls-Royce plc's competitive and proprietary information, all figures and data presented in this dissertation have been changed, are for the purpose of example only, and do not represent actual Rolls-Royce data.

Abstract

The market place in which Rolls-Royce Energy currently operates in is highly competitive. This means that the management of inventory is becoming ever more important, especially when the life cycle of Energy gas turbine engines can be as long as thirty years which are supported by Rolls-Royce's aftermarket business.

The purpose of this dissertation is to review and evaluate the management of inventory in Rolls-Royce's Energy business to determine methods that can be introduced to improve the inventory turnover rate bearing in mind that the company operates an Enterprise Resource Planning system which has standard measures applied that may not necessarily suit all areas of the Rolls-Royce business.

The following practical recommendations to improve inventory turnover within the Rolls-Royce Energy business have been drawn from the research findings and literature review:

- Implement the ABC inventory classification technique to ensure more focus on the parts that generate revenue for the business.
- Implement systems to better manage order quantities in the supply chain to ensure costings are transparent across the whole supply chain. Also ensure that capital is not tied up in inventory that is not going to be utilised.
- Materials that are held for insurance type purposes, which although critical for maintaining customer service levels through speed of delivery, impacts inventory turnover, so assess whether these parts could be better managed by being outsourced. This enables parts to be available at short notice but without the inventory sitting on the books.

Table of Contents

List of Figures

List of Tables

Acknowledgements

Many people have provided help and support to the author during the completion of this dissertation and he would like say a heartfelt thank-you to the following people:

- My partner for her patience, being a good listener, providing support with proof reading.
- My manager, team colleagues, team members and other course members from Rolls-Royce for their support during the period of this dissertation.
- Dr Jane Guinery, my academic supervisor at The University of Nottingham Business School, for providing a structure for this dissertation and her advice and encouragement over the last three months.
- Rolls-Royce for creating the opportunity by providing the sponsorship and for their commitment to my personal development over the last few years.
- The University of Nottingham Business School staff for developing awareness of how global supply chains operate in complex manufacturing environments.

Glossary

APICS	American Production and Inventory Control Society
CFBU	Customer Facing Business Unit
CLM	Council of Logistics Management
EOQ	Economic Order Quantity
ERP	Enterprise Resource Planning
GE	General Electric
GR	Good Received Processing Time
GT	Gas Turbine
GTS	Gas Turbine Spares
ICC	Inventory Carrying Cost
JIT	Just-in-Time
LTSA	Long Term Service Agreement
MFD	Manual Firming Dates
MOQ	Minimum Order Quantity
MRP	Material Requirements Planning
MRPC	Material Requirements Planning Controller
MRPII	Manufacturing Resource Planning
P&W	Pratt & Whitney
PDT	Planned Delivery Time
PG	Package
PGS	Package Spares
PTF	Planning Time Fence
RRE	Rolls-Royce Energy
S&OP	Sales and Operations Planning
SAP	SAP is the German abbreviation for 'Systeme, Anwendungen, Produkte in der Datenverabeitung'
SCU	Supply Chain Unit
SORB	Sales and Operations Review Board
TOC	Theory of Constraints
TRLT	Total Replenishment Lead Time

Chapter 1 – Introduction

1.1 Rolls-Royce Background

Rolls-Royce plc is a global business providing integrated power systems for use on land, at sea and in the air - with leading positions in Civil Aerospace, Defence Aerospace, Marine and Energy markets its technology is applied over a wide range of products generating high-value services throughout their operational lives.

Since the company was privatised in 1987 as part of the Conservatives government aim of reducing state involvement in business organisations, it has acquired a number of new businesses across its business functions; from Cooper Energy Services and Vickers in 1999 in the Energy market, to ODIM in 2010 in the Marine markets and during 2011 has formed a joint-venture with Daimler to make a bid for Tognum a German engine maker with applications in marine, land, rail and energy markets.

The company operates in a competitive market place, with a number of large competitors such as General Electric (GE), Pratt & Whitney (P&W), Siemens, to name a few of their key competitors manufacturing competitors, but the company also has extensive service operations so is also competing with major service providers such as Lufthansa Technik, TC Power.

Annual sales of over £10.1 billion and a forward order book of over £59.2 billion (2010 Annual Report), there are now more than 55,000 Rolls-Royce engines in service worldwide. Typically Rolls-Royce product and service lifecycles can span thirty of more years. Increasing volumes of engines are sold with Long-Term Service Agreements (LTSA) meaning Rolls-Royce now provides service capabilities throughout the life of the engine. These capabilities range from field maintenance, support services, provision of replacement parts, equipment overhaul services, component repair, and data management services. Services revenues account for more than half of Rolls-Royce group revenues, compared to 40 per cent ten years earlier. With greater revenues being achieved through services, it is essential for Rolls-Royce that it is able to understand its market, ensuring all requirements from customers are met on-time and in full.

Though there are significant barriers to entry in the manufacturing environment and with more and more engines now being sold with LTSA packages this means to grow market share Rolls-Royce must be able to meet its customer commitments throughout the life of its products. This means having the products available as and when customers require them for the overhaul of their products, or for engines with LTSA it means ensuring Rolls-Royce itself understands what demands its needs to fulfil to keep engines in operation.

1.2 Inventory Management

Inventory management plays an important role in establishing how successful a company and its supply chain is. All supply chains are built to support customers either internally or externally to the organisation. Customer needs have to be satisfied through the effective coordination of materials and information flows extending from the marketplace, through the organisation and down the supply chain to the raw material suppliers. Material flows represent the supply of product through the supply chain, in response to meet customer requirements. Information flows are concerned with the transfer of data through the supply chain, as this enables other parts of the supply chain to plan production and material requirements to meet demand requirements.

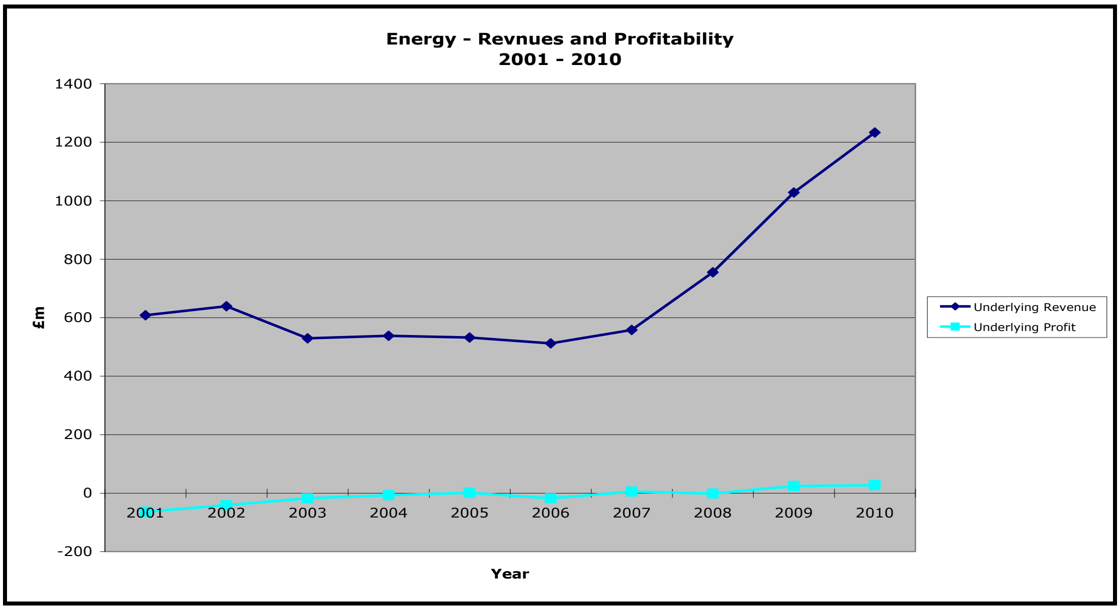
Inventory is a major use of capital within an organisation, and a primary objective of good inventory management is to increase the overall profitability of the firm. It’s essential however that the organisation has the correct levels of inventory required to support customer requirements throughout the organisation. Many organisations have failed by having the incorrect levels of inventory. This does not mean that having inventory is wrong, far from it, what the business needs to do is accurately plan what is required to ensure customer requirements are fulfilled. Having too little inventory is as problematical for the firm has having too much inventory. Inventory management needs to be about optimising what is required throughout the supply chain to ensure that the inventory held brings in revenue to enable the growth of the organisation.

1.3 The research arena

The dissertation was initiated by Rolls-Royce Energy (RRE) management team, identifying the need to improve the management of inventory in their aftermarket business. RRE identified inventory turnover was lower than expected, considering the amount of capital invested and whilst some of the inventory levels are driven by business processes, such as the Enterprise Resource Planning (ERP) system other factors such as obsolescence and engine life cycles also impact the frequency of inventory turnover.

Figure 1 shows revenue and profitability information of RRE for the last ten years. Whilst underlying revenues have more than doubled, profitability has only marginally increased in comparison. It is therefore essential that RRE drives to improve inventory management across its supply chain, as inventory is a cost to the business. The dissertation will evaluate how inventory is currently managed, reviewing inventory theories to provide recommendations that RRE can use to improve inventory turnover.

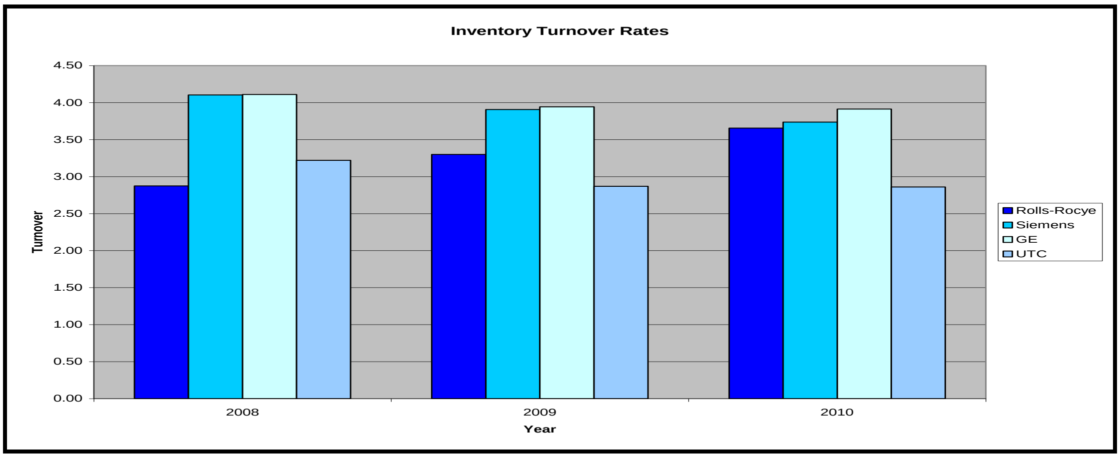
Figure 1: RRE Revenues and Profitability



Data from Rolls-Royce Annual Reports

Figure 2 illustrates inventory turnover of the key competitors, note P&W is owned by United Technologies Corporation (UTC) and it is the figure for UTC that will be used. As can be seen, Rolls-Royce's inventory figure overall has been increasing, but is still below GE and Siemens although the gap is narrowing. This means that key competitors are handling their inventory more effectively than Rolls-Royce, although care has to be taken especially with the data from GE as it is such a major conglomerate with a diverse range of business from gas turbine engines to television studios. Whilst it is clear Rolls-Royce needs to manage inventory more effectively, the next section will illustrate the business strategy as this may have implications for how inventory is managed across its supply chain.

Figure 2: Inventory Turnover Rates



1.3.1 Rolls-Royce strategy

The 2010 Annual Report and internal information demonstrate that Rolls-Royce strategy is to focus on the following core principles with the main criteria listed below. Appendix 1 provides a full breakdown detailing all of the information:

- **Develop a competitive portfolio of products and services**

  With 49 major engineering programmes and involvement in many of the future projects in the markets it serves.

- **Invest in technology, capability and infrastructure**

  During the last five years, the company has invested £4 billion in R&D. The company continues to invest substantially in employee development, and invests £300 million a year in capital projects.

- **Grow market share and installed product base**

  With average life spans of 25 years, gas-turbine engines enjoy long product lives which generate attractive returns over the life cycle of the product.

- **Add value for our customers through the provision of product-related services**

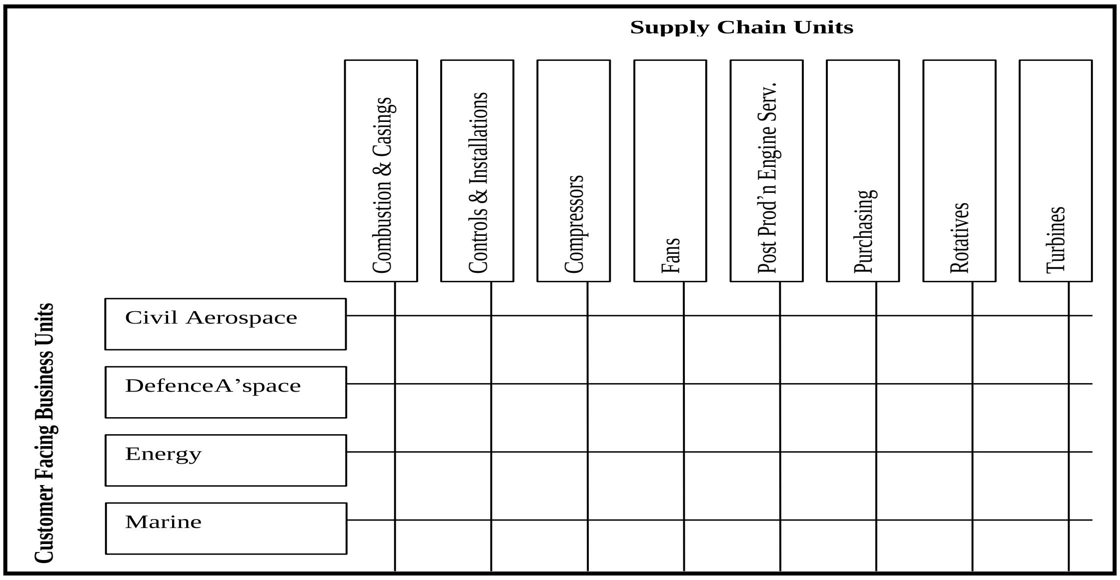
  The company seeks to add value for its customers with aftermarket services that enhance the performance and reliability of its products.

If a business is to compete successfully, it has to be able to improve continuously to create superior value, more efficiently than its rivals. Knowing which improvements to make and where to make them is therefore very important in ensuring its scarce resources are deployed to best effect. For this reason the management of inventory is becoming ever more important as poor inventory management has serious repercussions in a competitive marketplace and the way inventory is managed will be discussed in further detail throughout this dissertation.

1.3.2 Rolls-Royce organisation structure

The basic business structure of Rolls-Royce is split into Supply Chain Units (SCU) and Customer Facing Business Units (CFBU) see figure 3. The SCUs provide the manufacturing and sourcing of products whilst the CFBUs are responsible for the marketing and distribution of products. The CFBUs are supported by a Services function providing aftermarket support services from the sale of spare parts, equipment overhaul services, component repair, data management, field support equipment leasing and inventory management.

Figure 3: Rolls-Royce Business Structure



1.4 Overview of Rolls-Royce Energy

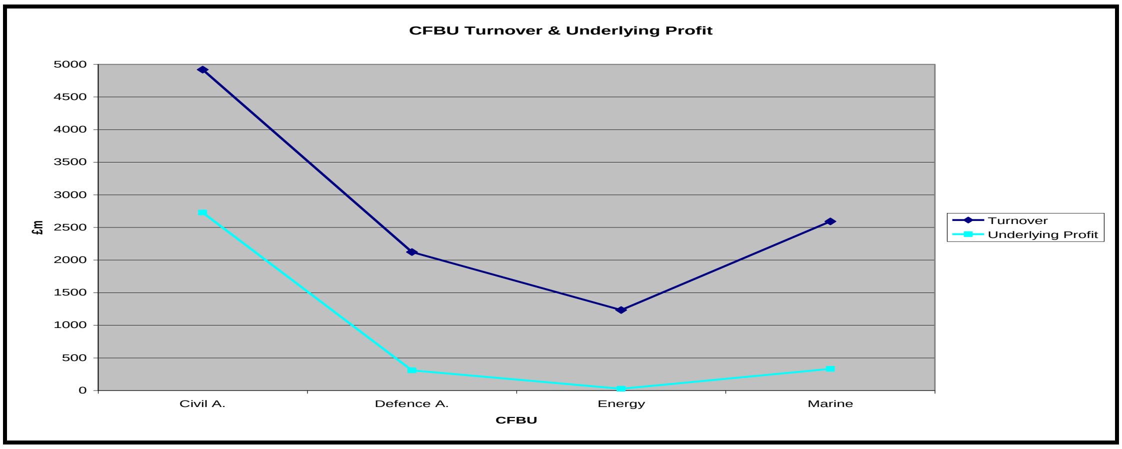
Having outlined that the request for this dissertation to be undertaken was at the request of RRE, this section will provide an overview of RRE business.

RRE supplies gas turbines, compressors and diesel power units as well as having responsibility for the development of Civil Nuclear capabilities. The business supports power system solutions for onshore and offshore oil and gas applications as well as an increasing presence in electric power generations; appendix 2 provides a summary of the key product portfolio. RRE products can be found in more than 120 countries.

RRE is a global business in its own right with gas-turbine engines manufactured in the UK and Canada, Package Equipment manufacture and assembly in United States of America with spare parts provision being maintained in the Untied Kingdom.

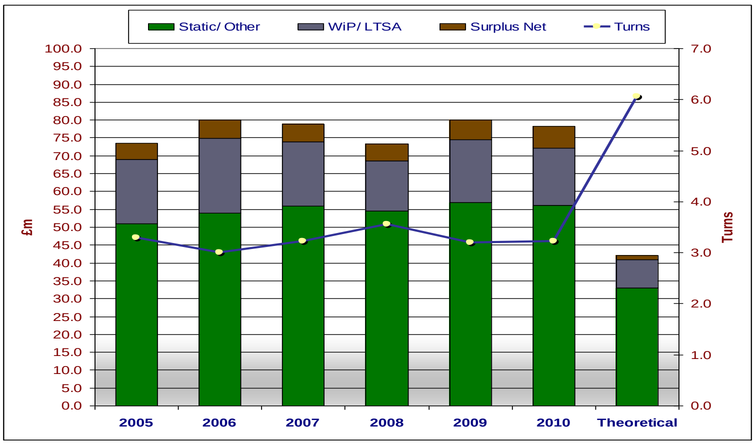
The 2010 Annual Report illustrates RRE performance with underlying revenue of £1.2 billion and profit growth of 13 per cent over 2009. Within the services division demand for products and services is continuing to grow, attributing revenues of £542 million, a 15 per cent increase since 2009. Figure 4 demonstrates turnover and profitability of all of Rolls-Royce's CFBU's shows that RRE is the smallest of CFBUs in Rolls-Royce.

Figure 4: Rolls-Royce CFBU Turnover & Profitability



If inventory management is seen to be a problem by Senior Managers its important to calculate and look at inventory turnover information. Figure 5 using information from the last six years shows that inventory turnover has averaged 3.2 turns per year, although the aspiration is to achieve six turns per year. The stock turnover (Walton & Aerts 2006) calculation is achieved by dividing the average cost of goods sold by average inventory. Currently the aftermarket demand forecast is generated by two planners, who have responsibility for managing 10,000 aftermarket parts.

Figure 5: RRE Stock Turnover



1.5 Problem definition

RRE is under going a major transformation programme as the company seeks to design, develop and deploy improved ways of working. This will impact the business from customer order through delivery of all equipment, including supplier interfaces. As part of the overall strategy of the improvement programme the business has recognised that the management of inventory will play a significant role in enabling RRE vision of being the Customers' first choice for Distributed Power and Compression System Solutions. Although revenues are rising with increasing numbers of engines being sold with LTSA's its important for the organisation to improve the ways inventory is managed in its supply chain. With more engines being sold if the current situation continues this will ultimately reduce the profitability of RRE as inventory ties up capital.

Current system processes at Rolls-Royce that were developed during the role-out of ERP may also no longer be fully suitable as increasing revenues are being driven through the services infrastructure. Whilst Original Equipment Manufacture (OEM) is reasonably predictable due to long order lead-times, the same can not be said for the aftermarket business which means orders have to be fulfilled within 90 days which has resulted in excess inventory being carried on certain parts and not enough of others. If the impact of these problems can be reduced, this will improve the turnover of inventory in the RRE business and will also help to generate additional profits for Rolls-Royce plc overall.

As mentioned previously in the information about RRE, one way of measuring inventory is to assess inventory turnover rates. Figure 5 earlier demonstrated that on average RRE is only turning inventory over 3.2 times per year, whilst the Civil Aerospace is able to turn inventory over at least eight times per year. Therefore, RRE management have been tasked with getting the inventory turnover rate 6.0, to be achieved by 2014.

In summary the problem that will be researched is to evaluate what RRE can do to improve its inventory turnover rates whilst at the same time ensuring that customer service is not impacted. This has to be done in accordance with general Rolls-Royce ERP processes although these can be challenged if they do not support the overall requirements of the RRE business.

1.6 Purpose

The overall purpose will be to determine how RRE should improve the management of inventory whilst ensuring that customer service levels are not compromised. Whilst the aspiration is to more than double the inventory turnover rate, RRE must take into account other business processes that may need to be challenged if it can be shown they do not support the business.

1.7 Limitations

As the RRE business incorporates a number of different business areas, this dissertation will primarily look at the gas-turbine aftermarket business. Due to time constraints, and in order to manage the dissertation only small number of inventory processes will be evaluated. It is envisaged that any lessons learnt from the aftermarket business could with further investigation and evaluation be applied elsewhere in RRE portfolio. In part due to Rolls-Royce's business processes it is necessary to include a section on the development of these processes to demonstrate the problems that need to be overcome when looking at introducing change into a structured organisational environment.

1.8 Dissertation structure

Chapter 1: Introduction. The aim of this chapter is to give an introduction to the research of the project. The company being reviewed and its operating structure are presented in this chapter. The problem definition, purpose statement and any limitations are defined.

Chapter 2: Framework & Literature Review. The aim of this chapter is to provide an overall framework with regards to the management of inventory and the areas that RRE needs to address if it is to improve the number of times inventory turns over within the business. This section will also address the key areas that need to be assessed as ways of improving inventory management within the business. This section will also provide a literature review, identifying the key areas that will help drive inventory improvements through the business.

Chapter 3: Rolls-Royce Business Processes. The aim of this chapter is to provide a summary of Rolls-Royce's business process model and how this aligns to the Enterprise Resource Planning system. This section notes how ERP systems have been developed as whatever Rolls-Royce Energy does to improve its business, must operate in conjunction with the ERP systems utilised in the organisation.

Chapter 4: Research Structure. The aim of this chapter is to summarise the questions to be researched to enable Rolls-Royce Energy improve its inventory turnover figures.

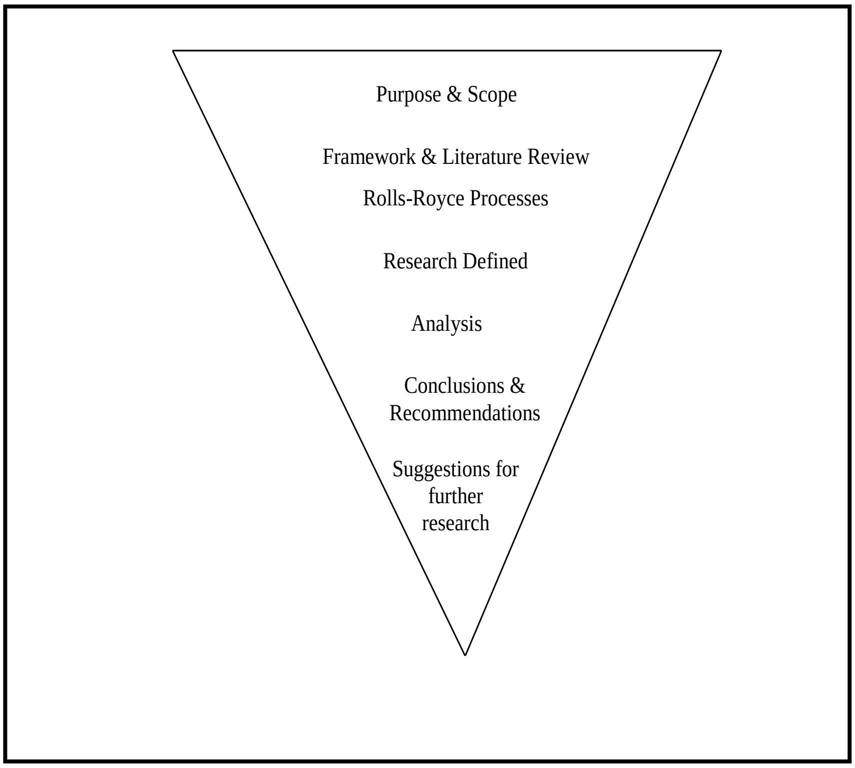
Chapter 5: Analysis. This chapter analyses the current workings of Rolls-Royce Energy by considering how inventory is currently managed and what changes will need to be introduced to improve the inventory turnover figures.

Chapter 6: Conclusions & Recommendations. This chapter provides conclusions to the research questions and provides recommendations and timescales for implementing changes to the way Rolls-Royce Energy manages inventory.

Chapter 7: Suggestions for further research. This chapter provides suggestions for further research, acknowledging that what is established through this research will lay foundations for further improvement activities to be carried out.

The disposition of this thesis is presented in figure 6.

Figure 6: Thesis Disposition



Chapter 2 – Framework & Literature Review

This section will provide a framework and literature review of the key inventory management measures that should be evaluated as ways of helping to improve inventory turnover in RRE.

2.1 Inventory Management Definition

Inventory is defined as "those stocks or items used to support production (raw materials and work-in-process items), supporting activities (maintenance, repair, and operating supplies) and customer service (finished goods and spare parts)" (Bozarth & Handfield, 2008). Inventory management is the activity which organises the availability of products across the supply chain.

Lowe (2002) defines inventory management "The effective management of stock, materials, parts and finished products, including additions and deletions (i.e. control of movement in and out). Essential for determining capital investment returns and viability of stock levels and for the avoidance of opportunity cost (i.e. money tied up in stock that could be better used)."

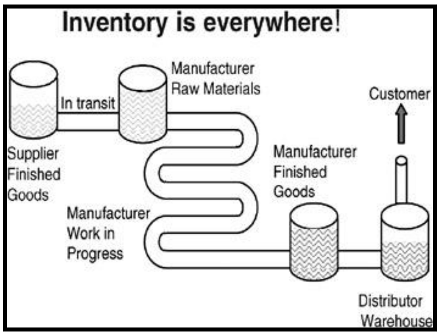
The definition by Lowe makes it clear that inventory management must be effective and relate this well to looking at the costs associated with having money tied up in the wrong products. Senior management will often ask why a business needs to carry inventory, especially if they could get better returns by investing the capital elsewhere. There is also a risk that the inventory may become obsolete which means the capital invested will not be realised.

Muller & Langenwalter (2004) in their work on the fundamentals of inventory management, note the importance for organisations like Rolls-Royce that sell inventory directly to customers that the inventory is where value to the customer is added. For customers buying a Rolls-Royce gas-turbine engine, Rolls-Royce is the principal provider for spare parts. Within Civil Aerospace this situation has recently changed with the aftermarket service for the RB211-524 legacy engines being outsourced to Avail who in turn is owned by Boeing.

2.2 Requirement for inventory

Mangan et al (2008) demonstrate inventory can be found everywhere, see figure 7. Inventory moves between locations, and for any business there is a requirement to keep the system balanced to ensure that when an order is received, it can be supplied in a timely manner. Inventory takes a variety of different forms ranging from raw materials, work-in-process (WIP); supplies used in operations, as well as finished goods.

Figure 7: Inventory is everywhere



From Mangan et al (2008)

The way inventory is managed in supply chains, has altered over the years according to Muller & Langenwalter (2004). Traditionally firms carried inventory in order to meet their requirements, however with the development of lean and just-in-time systems, inventory is no longer seen as needing to be held in stock but can flow through the supply chain. Willemain et al (2004) research into forecasting of inventory concludes that within aftermarket environments there is an ever greater need to ensure you have inventory in the correct place to satisfy all customer requirements, but especially the end customer.

Bianco's (2006) research into Wal-Mart defines the importance of ensuring the flow of material in the supply chain is balanced between supply and demand, such that key manufacturers such as Procter & Gamble are able to assess store sales information for the last two years, this supports the view of Willemain et al noted earlier. This sharing of information through supply chains is important and is possible an area of overall weakness within Rolls-Royce where data is not shared proactively across the supply chain. This means the whole supply chain is constantly trying to anticipate customer requirements, even though reliable information is available to be shared.

The Rolls-Royce supply chain is very different to Wal-Marts and the fact that lead times within Rolls-Royce can be as long as two years, means that the supply chain is less able to react quickly to demand changes, which means that inventory is carried at various different points, so that when an order is received the stock will be available to be shipped to meet the customer delivery date.

Whilst inventory can be held anywhere in the supply chain, it will be useful to identify why there is inventory in the supply chain. It can not be denied that in RRE inventory is found in numerous parts of the supply chain.

Table 1 summarises the main reasons identified for having inventory in the supply chain as identified by Muller & Langenwalter (2004), Waters (2003).

Table 1: Reasons for Inventory

Term	**Description**
• Process Buffer	• Inventory used to buffer processes at strategic points. This takes into account that processes through the supply chain may have different requirements, the buffer therefore support the operations process.
• Fluctuations in demand	• This inventory allows suppliers to satisfy customer demand that is higher than anticipated. • Inventory holdings can be reduced if supply chain lead times can be shortened.
• Unreliability of supply	• Inventory can and should be used to act as a buffer against poorly performing suppliers. • In the long run, work with suppliers to insure their reliability. • Drive suppliers to improve delivery performance, working with suppliers to implement improvement activities, e.g. Six-Sigma.
• Price protection	• Buying larger batches at one time has been used to hedge against future price increases. • Negotiate pricing and long-term contracts with key suppliers, but you request multiple deliveries.
• Quantity discounts	• Discounts can be obtained for buying larger quantities, and the impact is similar to price protection. • Need to ensure that all costs involved are evaluated before accepting a quantity discount.
• Lower ordering costs	• In the past companies have looked at ordering costs as a necessary cost that is traded against holding costs. • Today, the aim is to reduce non-value adding activities within the supply chain and then calculating total costs and lead times.
• Improve customer service	• Operating systems usually cannot be designed to economically respond to requests for product in an instantaneous manner. Inventories provide a level of product availability, which, when located in the proximity of the customer, can meet a high customer service requirement.

Adapted from Muller & Langenwalter (2004)

As Muller & Langenwalter identifies, there are many reasons on why a business such as Rolls-Royce requires inventory in the supply chain. What also needs to be examined is how these reasons are enacted by the organisation. In Rolls-Royce for example, the Purchasing (Buyer) functions objective is to obtain parts at the lowest cost possible which can undermine the CFBU function who only want enough parts to satisfy demand requirements.

2.2.1 Types of Inventory

Having identified why a business has inventory, this section identifies the different types of inventory that a company can have. Slack et al (2001) reviewed the different types of inventory that maybe held within the supply chain, see table 2 below.

Table 2: Types of Inventory

Inventory Type	**Characteristics**
Buffer Inventory (also known as Safety Inventory)	• Compensates for the uncertainties between supply and demand. • As demand can be difficult to forecast accurately, decision is taken to have a certain level of stock. This stock is there to cover against the possibility that demand will be greater than expected during order lead times. • This buffer therefore provides for these uncertainties.
Cycle Inventory	• Inventory occurs because one or more stages in the operation cannot supply all the items it produces simultaneously. • Operation therefore produces in batches which must be large enough to satisfy the demand for when parts are not being produced.
Anticipation Inventory	• Used where there are significant demand fluctuations which are predictable. • Rather than make the product to meet the requirement, products are produced throughout the year to meet the peak demand,
In-transit Inventory	• Inventory that is en-route from one location to another.

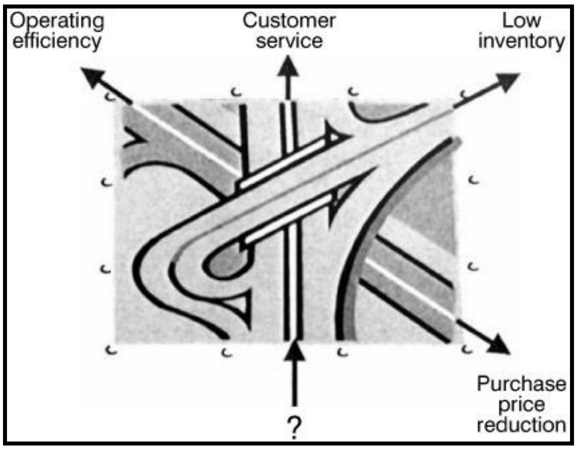
Adapted from research by Slack et al (2001)

Whilst different areas of the business, have different ideas and ideologies of why the company needs inventory. Slack et al (2001) makes the important note that it doesn't matter where in the supply chain inventory is, it exists because there is a difference between timing the rate of supply and demand. In an ideal world supply and demand requirements would be matched which means inventories would not need to be held. This would be the perfect world example having supply and demand equally matched. In most organisations, RRE included demands are not equally matched, even though thousands of pounds have been invested in trying to get to that point. The next section evaluates some of the issues organisations such as Rolls-Royce has with managing inventory.

2.2.2 Issues with Inventory

Rolls-Royce for many years has tried to improve the management of inventory. This is done by coordinating the purchasing, manufacturing and distribution functions to meet the marketing needs (Wild, 2002). Inventory enables the business to support customer service, logistic or manufacturing activities in situations where the manufacture of products is not able to satisfy overall demand requirements. Wild (2002) provides a useful summary stating that inventory management exists at the crossroads in the activities of the company (figure 8).

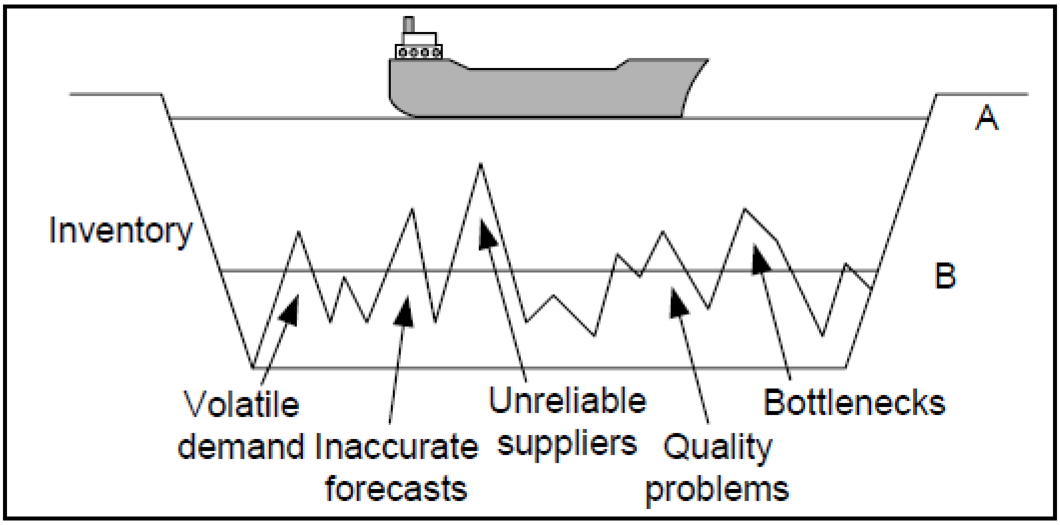
Figure 8: Which direction?



Wild (2002)

Whilst Wild supports in general the requirement to have inventory, Christopher (2005) takes the view that inventory can be used to hide inventory problems. Christopher uses the theory that many Japanese manufacturing companies have used. In "The Japanese Sea" where the concept is to wherever possible remove inventory to identify problems that companies have with their logistics processes. The theory is used to demonstrate that where inventory is removed from the supply chain, problems will be exposed. Figure 9 below demonstrates the "Japanese Sea" model as perpetuated by Christopher. Whilst the theory is very well understood, for many businesses Rolls-Royce included the organisation would be very brave to remove inventory to expose these problems, although that is not to say that if you want to highlight a significant weakness in your supply chain that the company may decide to reduce inventory in certain areas.

Figure 9: The Japanese Sea: Inventory hides your problems



Source: Christopher (2005)

Rolls-Royce carries inventory as a way of ensuring customer requirements can be fulfilled as and when required. By holding inventory, lead-times can be shortened; it also assists in providing operational flexibility, by providing buffers where input and output rates are not aligned. From a manufacturing perspective, inventory can be used to store capacity that would other be lost. The Civil Aerospace market is a prime example of a business that is directly impacted by the economy. In economic downturn in recent years has meant that demand for spare parts has fallen, but rather than shutting off capacity, Rolls-Royce has decided to invest in building stock on key components. The reason being as the economy revives and the demand for aircraft increases, aircraft that have been stored will come back into service and will require overhaul. If Rolls-Royce had decided not to invest in building inventory, the supply chain would struggle to meet the demand requirements.

Companies that have developed lean and just-in-time (JIT) systems only have a requirement to pull stock as and when it is required. Interestingly, whilst having JIT, and or lean supply chain is beneficial any disruption to the supply chain can have a dramatic impact on the ability especially for production systems. Note the recent earthquake in Japan has resulted in the major manufacturers Honda, Toyota having to suspend production as the supply chain has been severely disrupted.

2.2.3 Views of Inventory

Inventory means different things to different parts of the same organisation, table 3 demonstrates different organisational functions and what they believe is the role of inventory which has been identified by Muller & Langenwalter's (2006) research into inventory control.

Table 3: Business function views of inventory

Business function	Viewpoint of Inventory
Sales	• Good inventory management enables the company to have available any product for immediate sale, for as large quantity as demanded by the customer.
Purchasing	• Good inventory management is based upon obtaining lowest possible price for products. • Buying in bulk can reduce purchase prices. • View warehouse function as a way of storing products obtained at lowest price.
Finance	• Usually the area that is not keen on inventory. • See inventory as a way of consuming working capital that upsets cash flows. • A benefit of inventory is the ability to make provisions for unusable materials which can be adjusted to modify profit figures.
Quality	• Usually the area that is perceived as slowing down the movement of inventory while checks are undertaken.
Management	• See inventory management as a source of information.
Distribution	• See inventory as something that has to be stored. • Often seem to be blamed when inventory is not in the right place at the right time.

Adapted from Muller & Langenwalter's (2006)

Having established the needs for inventory, how are the levels of inventory measured to ensure that the correct inventory is being held. The next section will look at the types of metrics that are found in most organisations that relate to the management and planning of inventory.

2.3 Inventory Metrics

Lee & Billington (1992) work into managing supply chain inventory believe that one of the biggest mistakes organisations have is the lack of metrics around the supply chain. More recent research by Keebler & Plank (2009) notes how the Council of Supply Chain Management Professional (CSCMP) noted that still most US firms do not have in place comprehensive measures of logistics (supply chain) performance. The research however notes why inventory metrics are important as organisations can use the information to drive down operating costs. They also make reference to the Supply Chain Operations Reference (SCOR) which although has many merits is more about showing overall strategic performance, so will not be discussed as part of this dissertation, although longer term the application of SCOR could provide business benefits.

Within RRE whilst there are numerous supply chain measures in place, the problem lies in the fact that the measures tend to operate in isolation. This provides an inconsistent measure across the business. For example whilst RRE is measuring inventory turnover, no measures currently exist to measure customer response times, although it is believed within the management team that there is a problem.

Whilst tackling ways to improve inventory turnover as a key business driver, it's important to evaluate other types of metrics available so that going forward time can be taken to improve the areas that will provide the largest benefit to the business.

Muller's (2003) book on the fundamentals of inventory management analysed the typical measures that can be found within the business, see table 4. The metrics provide information about how well the company is deemed to be managing inventory, but a note of caution is that if you are comparing different companies you need to assess that what you are measuring is like for like. For instance, whilst a retailer like Tesco is likely to have a very high inventory turnover figure if you compare this to Rolls-Royce whose figure is far lower you would say that Tesco is better at managing inventory. The problem lies in the fact that Tesco is selling fast moving consumer goods that have very short shelf-lives whereas Rolls-Royce's products are largely non-perishable.

Shapiro's (2007) research into modelling the supply chain, says companies are now using metrics either as performance measurements, or as ways to incentivise to achieve better performance. Whilst metrics are important they need to be fully understood by all to ensure the correct measures are put in place that supports company and customer requirements.

Table 4: Inventory Metrics

Metric	Definition
Inventory Turns	Number of times that a company's inventory cycles or turns per year. Calculated as Annual cost of sales divided by Average Inventory Levels
Total inventory (£) or Total inventory days	Total amount of inventory in the supply chain inclusive of raw materials, work-in-progress, and finished goods.
Obsolete inventory	Amount of obsolete inventory as a percentage of sales or total inventory
Manufacturing lead-time	The time required once the product began its manufacture until the time it is available to the customer
Supplier lead-time	The time required between ordering the product and receiving the product from a supplier
Inventory flow rate	Ratio of the inventory level to average inventory cycle time
Working inventory rate	The amount of working inventory as a percentage of total inventories

Adapted from Muller (2003)

2.3.1 Inventory Turnover Metric

Having identified in the introduction, the management of RRE is concerned about is the inventory turnover rate. This measures how frequently the stock is used within a given time period. The time period used by Rolls-Royce is twelve months, but depending on what you are measuring can range from days, weeks, months are any combination.

2.3.2 Obsolete Inventory Metric

Within any supply chain there are elements of stock that is classed as being obsolete, i.e. it has no purpose in its current format. This type of inventory has to be managed as high levels of obsolescence will indicate poor performance especially within regards to demand management. For RRE obsolescence is a major concern because this inventory will never be sold and financially has to be provisioned for from an accounting perspective. RRE has for many years kept obsolete items in stock to act as a contingency just in case there is a future demand for the stock, whilst the Civil Aerospace business has developed a process for moving this type of material to a third party provider to manage. This effectively takes the inventory off the books so when inventory turnover is calculated against cost of goods sold the turnover figure will improve.

2.3.3 Supplier Lead Times

Lead times are a major contributor to inventory levels in RRE. Waters (2003) work on inventory control notes a number of reasons for lead times in the supply chain, see table 5:

Table 5: Causes of Lead Time

Cause	Definition
Time for order preparation	• This is the time involved in processing an order. • Depending on the type of order will determine lead time. For example if an RRE item needs to go out for a quote this time needs to be added to the response date provided to the end customer.
Time to get the order to the right place in suppliers.	• In the past orders have often not got to the correct person in the organisation meaning the order is not processed in a timely manner. • With development of automated ordering systems such as EDI, orders should now be sent directly to the firms ordering department helping to reduce lead times.
Time at the supplier	• This is the time needed for the supplier to process and prepare the order. • Time will depend on whether the item is make-to-stock or male-to-order at the supplier
Time to get the materials delivered from suppliers	• If supplier is local this can take a few hours, but with global supply chains freight times have lengthened.
Time to process the delivery	• This is the time taken between an order being received and it being available for use. • This may include time taken for quality inspection, cataloguing and movement.

Lead times can therefore vary from days to years; indeed it is not uncommon across Rolls-Royce to have lead times of at least two years. This impacts the amount of stock that needs to be carried to ensure customer requirements can be fulfilled in a timely manner. The next section will review costs involved in carrying inventory.

2.4 Inventory Costs

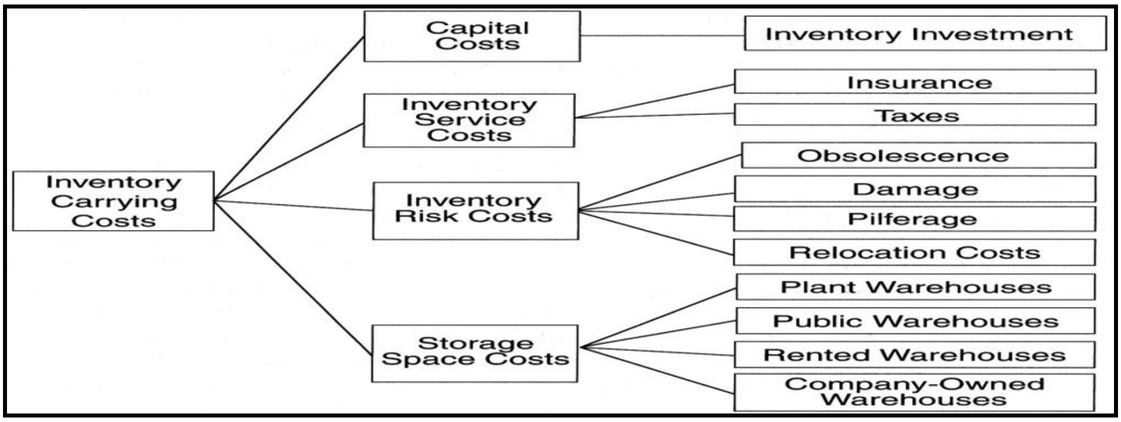
There are a number of elements of inventory holding costs that businesses need to be aware of as defined by Rushton et al (2006), Wild (2002), appendix 3 provides the formulas for working out the inventory costs:

- Capital cost: the cost associated with the physical stock. This is the financing charge that is the current cost of tying up capital that the business might have generated a better rate of return by investing elsewhere other than in holding stock.
- Storage cost: the cost of space, handling and associated warehousing costs involved with the physical storage of product.
- Reorder cost: these include set-up costs associated with the manufacture of an individual item. This includes the cost of raising and communicating an order, as well as the costs of delivery. Note the reorder cost applies regardless of order size.
- Service cost: the cost of stock management such as insurance and taxes. Insurance cost is carried as a protection against losses that may arise from fire, storm, or theft.
- Risk cost: this includes accounting for shrinkage (theft), deterioration of stock, damage or obsolescence.
- Shortage cost: the cost of not satisfying a customer's order. This cost is often difficult to measure and at worst maybe ignored but it attempts to reflect the penalty of not holding sufficient stock of a product, which may lead to lost profit due to lost sales. This can also result in loss of future sales, loss of reputation as well as incurring additional costs for satisfying urgent delivery requirements.

2.4.1 Inventory Carrying Cost

Inventory Carrying Cost (ICC) is defined by Harding (2004) as the cost to carry inventory measures the overhead that a business carries to support its inventory. This includes the money spent as capital outlay but also includes monies spent on upkeep whilst inventory sits in your possession. Harding refers to the fact that the longer inventory is there, the more it costs to keep. Goldsby & Martichenko (2005) in their work on the waste of inventory, recognise that inventory carrying costs represent both accounting costs and economic costs. They define accounting costs as "being explicit as it calls for a cash outlay and registers on the books of the company", whilst economic costs are "implicit, it does not necessarily involve a capital outlay, but rather an opportunity cost". Goldsby & Martichenko (2005) designed the following chart to illustrate the key components of ICC, see figure 10. All of these costs need to be assessed, for many organisations, Rolls-Royce included the true costs involved with carrying inventory are often neglected especially for items that are held for insurance. For RRE a sizeable proportion of stock that is held is held purely for insurance type items and whilst this is not wrong because from a forecasting perspective you would never be able to scientifically predict when stock will be required, but RRE needs to decide where this stock should be kept.

Figure 10: Inventory Carrying Cost



Goldsby & Martichenko (2005)

2.5 Inventory Control

This section will review how inventory is controlled through the manufacturing system.

2.5.1 Push System

The push system has been described as a top-down planning system. This is because production quantity decisions are taken from forecasted demands in the Master Production Schedule (MPS). Within the manufacturing system parts are released to the next station as quickly as possible. Hopp & Spearman (2004) define a push system as one that "has no explicit limit on the amount of work in process that can be in the system". Karmarkar (1991) summarises that push systems drive order release decisions by making assumptions about future demand requirements.

Push type systems are most commonly found in "make-to-stock" environments. The ERP system used by Rolls-Royce SAP is said to be a push type manufacturing system as stock is pushed through the system to the point of demand which is usually the CFBU plants.

2.5.2 Pull System

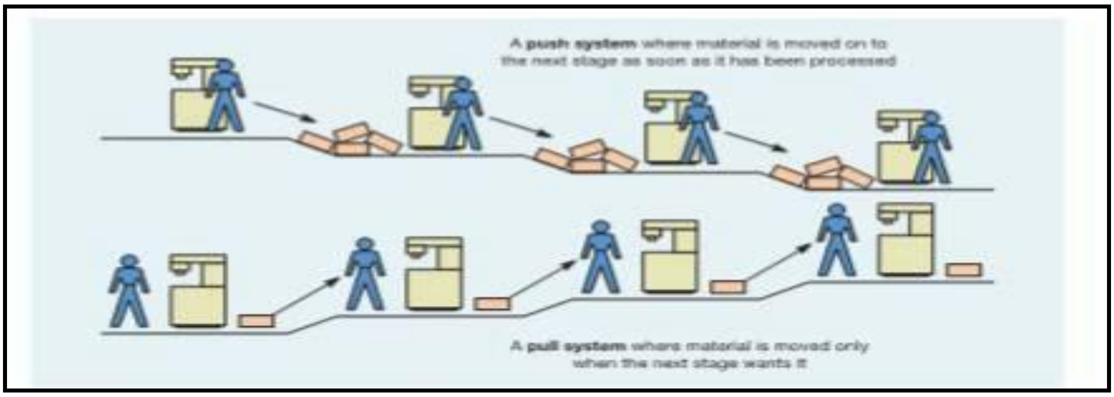
The pull system is where production is based upon an actual customer demand, compared to forecasted demand in a push system. Waters (2003) research into inventory control notes how pull type systems are often referred to as operating as 'just-in-time as operations only occur at the exact time they are required. Baudin (2004) says that pull systems are usually found in lean operating environments which are often using the same principles of just-in-time.

Ghrayeb et al (2008) demonstrate that each station within the production system should be treated independently as it will have its own supplier (the upstream station) and its own customer (the downstream station). When a customer order is placed, it is fulfilled from finished product inventory. This provides a signal (usually referred to as a Kanban) to trigger production of the upstream workstation to replenish the finished product inventory. Hylan & Wemmerlov (2002) research into manufacturing planning systems note that pull systems if tightly controlled are able to reduce inventory as well as being able to stabilise lead times. The research concludes however that although there are advantages pull systems require a large amount of discipline to work effectively. Any system with a very unpredictable demand signal will struggle to cope within a pull system. The aftermarket demand requirements within RRE are unpredictable which fluctuations on demand requirements.

2.5.3 Differences between Push and Pull System

Figure 11, demonstrates the differences of push or pull systems.

Figure 11: Differences between Push and Pull inventory systems

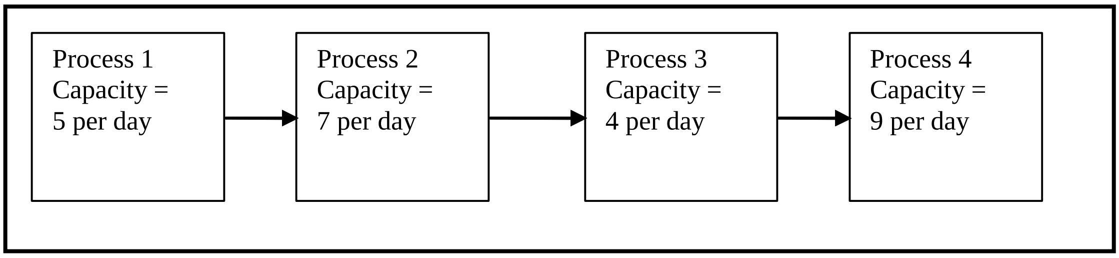


Slack et al (2001)

2.5.3 Theory of Constraints (TOC)

Another method that can be used to control inventory is a concept called Theory of Constraints (TOC), developed by Eliyahu Goldratt. Goldratt's premise is that all products and services are created through a series of linked processes, which is effectively a supply chain and evolves over time as with many management theories (Watson et al 2007). Each process step is said to have a specific capacity, and there will usually be a process step that constrains the overall capacity of the supply chain. Figure 12 illustrates Goldratt's idea showing a number of process steps with differing capacities.

Figure 12: Demonstration of capacity restraint on TOC



Adapted from Bozarth & Handfield (2008)

In figure 10, process 3 would limit the overall capacity of this process chain to a maximum 4 units per day. Bozarth & Handfield (2008) demonstrate in their work on TOC that pushing more than 4 units a day into the process will generate excess inventory in front of process three. Process 3 also limits what process 4 can produce. To improve the flow of inventory through this process, TOC people have suggested the following five-step approach to improving the overall throughput of the supply chain, see table 6.

Table 6: Improvement to throughput of a process supply chain

Step	Process
1. Identify the constraint	The constraint is not necessarily contained within the chain, it may occur at the customer. The constraint can either be a resource of policy.
2. Exploit the constraint	Need to carefully manage the constraint to ensure no time is lost at the constraint. They argue that any time lost at the constraint is lost throughout for the whole process chain.
3. Subordinate everything to the constraint	The effective utilisation of the constraint is the primary issue to be solved; everything else is of secondary importance.
4. Elevate the constraint	Find ways to increase the capacity of the constraint
5. Find the new constraint and repeat the steps	As new ways are found to resolve the constraint issue, a constraint will be found elsewhere that needs to be worked.

From the perspective of inventory management as a way to help improve inventory turnover part of the issue RRE has is that it is required to hold stock as finished part level to cover for demand uncertainty. The constraint would be length of time taken to complete a lower level assembly if a customer order was received for a part not in stock (note customers can order on a 90 day lead-time).

2.6 Inventory Models

This section will discuss a number of models that could be used to help improve inventory management in RRE.

2.6.1 ABC analysis

ABC system was derived from Pareto's 80/20 rule. Ballou (1992) researched how Vilfredo Pareto in 1897 whilst reviewing the distribution of income and wealth in Italy noted that a large percentage of total income was concentrated in the hands of a small percentage of the population, roughly in the proportion of 80 percent to 20 percent. A criticism of the ABC inventory classification though is that it does tend to ignore a large proportion of products. A comment often heard in Rolls-Royce when talking about the need to carry inventory is the following question: which part is the most important for the engine? The answer is the last one as the engine can not be assembled without all of the products. This means that if there is a lot of focus on high value parts but low value parts are ignored it will be the low value parts that start to cause problems.

In this technique, the most important products are placed into group A. This is based on them requiring the most amount of attention. The least important products are placed into group C, with all other products appearing in group B. Viale (1996) asks the following question "Which products (and which customers) generate 80 percent of the revenue?" The answer is that 20 percent of the products and customers generate 80 percent of the revenue. Table 7 below summarises the interpretation of Pareto's argument for inventory management.

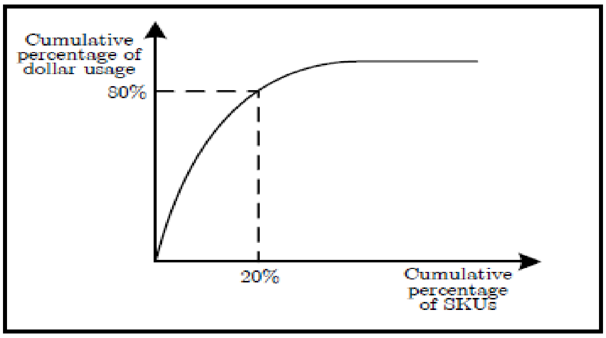
Table 7: The 80/20 Rule (ABC analysis)

20% of customers, products or parts =	80% of the company's revenue and inventory investment	These are called "A" customers "A" products "A" parts
30% of customers, products or parts =	15% of the company's revenue and inventory investment	These are called "B" customers "B" products "B" parts
50% of customers, products or parts =	5% of the company's revenue and inventory investment	These are called "C" customers "C" products "C" parts

From Viale (1996)

Whilst Viale applies the 80/20 rule across the board in respect of customer, parts or product, Chen et al (2008) detail how ABC analysis is calculated by assessing annual dollar usage of a product. Figure 13 below demonstrates the 80-20 classification.

Figure 13: Example of dollar usage distribution curve



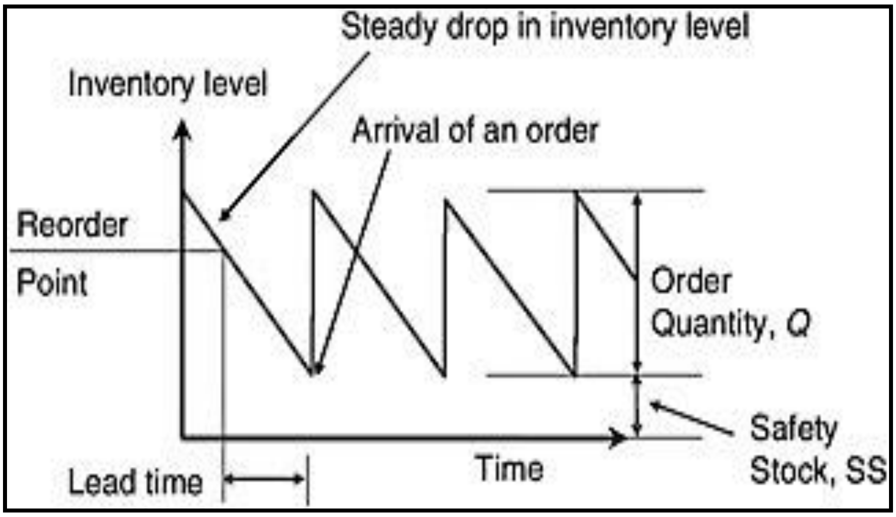
Chen et al (2008)

2.7.1 Economic Order Quantities (EOQ)

Waters (2003) says the EOQ model is used to answer the question of how much inventory should we order. The EOQ model has a long history according to Waters it was first mentioned by Harris in 1915 or Wilson in 1934.

The model works by trying to calculate how total costs can be minimised. Total costs include set up costs and the inventory carrying cost. Using this information determines the economic order quantity. The model also accounts for the fact that the overall stock holding of an item will vary over time as deliveries and orders are made from the stock. Figure 14 by Mangan et al (2008) demonstrates how inventory will vary over time.

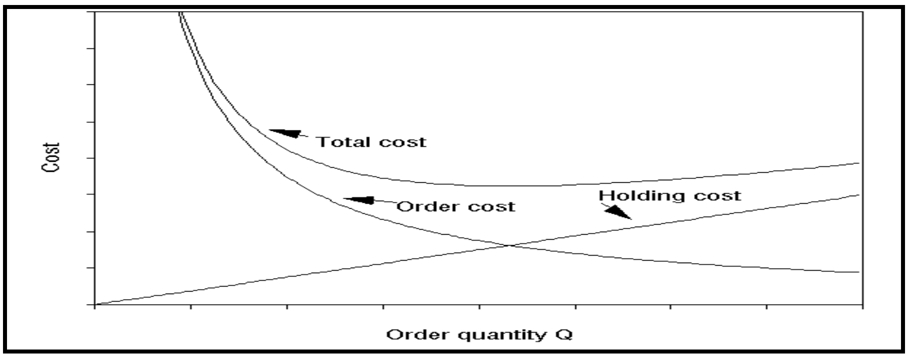
Figure 14: EOQ Model



From Mangan et al (2008)

Appendix 3 demonstrates a worked example of the EOQ model as defined by Waters (2003) and Slack et al (2001). The basic EOQ model provides a simple view that if orders are received infrequently and also have a high holding costs the overall total costs will also be high. Small frequent orders have higher reorder costs which again impacts the overall total costs. The compromise position to find the EOQ at the point where overall total costs are minimised see figure 15.

Figure 15: EOQ and Costs



Waters (2003)

Waters (2003) research into EOQ models identifies a number of problems which need to be worked when calculating the results. If set-up costs are high, the EOQ model will try to increase the overall batch size which although has advantages from the manufacturing perspective means that additional costs in regards to storing the excess capacity and also means that capital will be tied up in inventory which means the organisation can't utilise the funds elsewhere.

2.7.1.1 EOQ & Lead times

The basis EOQ model makes a number of assumptions, one of which is that once an order is placed, the materials arrive and can be used. In most manufacturing organisations, orders can not be fulfilled immediately and this implies the utilisation of a lead time which is classified by Waters (2003) as the total time between an order being placed and having the materials available for use. Table 8 illustrates the reasons that lead time occurs.

Table 8: Reasons for lead times

Reason	Definition
Order preparation	• Time taken to actually place an order. There is often a delay between the organisation deciding it requires something and the actual order being placed on a supplier. • Orders may need to go through a tendering process, especially if they are large and complex whilst routine repeat orders maybe generated automatically. • Within Rolls-Royce for example, commitment acceptance would be required before any order can be placed into SAP.
Order placement in the supplier	• Depending on the order method used, delays may be occurred getting the order to the correct person in the supplier.
Time at the supplier	• Time taken to process the orders and prepare items for despatch. • Is the product required made-to-stock or made-to-order which will impact time taken to supply.

Delivery	• How are parts going to be delivered? Rolls-Royce will generally use its supplier collection service, but for small vendors who are only visited once per week if the order misses the delivery collection day it may take a further week to be collected. • If parts are coming from the Far-East the lead time must take into account which shipment method is being used Air-Freight or Sea-Freight.
Process delivery	• Time taken between receiving an order in the warehouse to the stock being made available for the customer. • Due to rules and regulations for example new parts have to pass a First Article Inspection Report which may mean additional checks are undertaken on the product.

Adapted from Waters (2003)

From a customer perspective, the lead time needs to be as short as possible. As stated previously a customer placing an order on RRE will generally have to wait a minimum of 90 days before they receive their order, which compares to 5 days within the Civil Aerospace business. It would be expected that with a 90 day lead time most goods should be available as the due date arises, but often parts are still missing. To overcome this safety stocks are added into the SAP system to provide some form of protection.

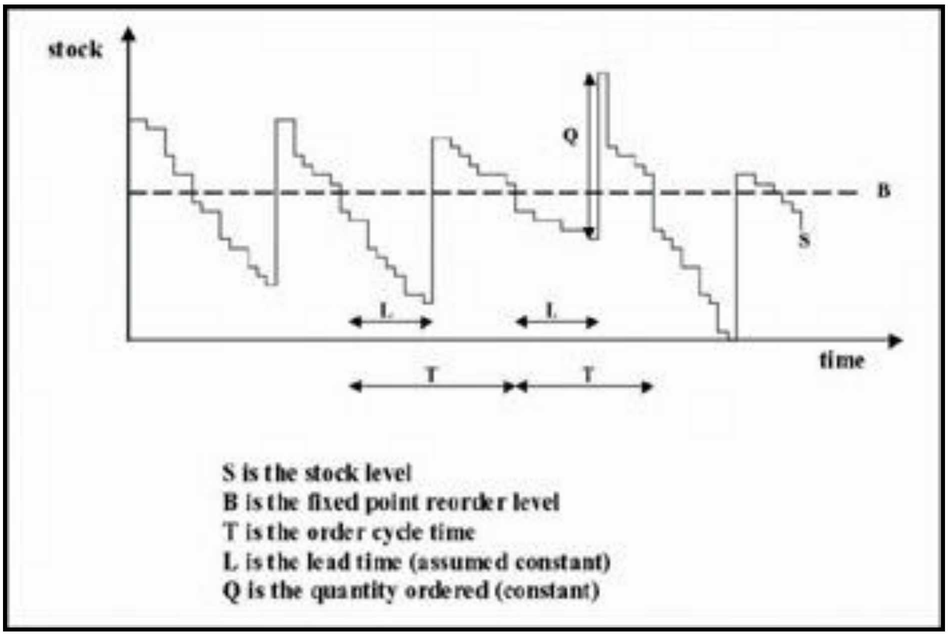
2.7.1.2 Reorder levels

Bozarth & Handfield (2008) recognise that whilst the EOQ can tell management how much to order, it does not tell them when to order. Winston's (2011) research into data modelling identifies that where demand is uncertain from an inventory point of the view the question arises of how let can you allow inventory to go before placing an order. If you set the reorder level too high then holding costs will increase, but if you set the point too low shortage costs will increase whilst holding costs are reduced. Ultimately as inventory management is ensuring customer service levels are maintained, the reorder point has to be set to ensure shortages are minimised.

If demand rates and lead times are constant the reorder point can be easily calculated, but in most organisations and RRE specifically demand and lead times are not consistent as manufacturing processes are not consistent which means parts may require reworking or concessions to be applied for, although it will be demonstrated later that the SAP system utilises constant lead times.

If lead time is presumed to be consistent as with SAP there is deemed to be no business benefit from carrying stock between production cycles. Each order is timed to be delivered just as the previous batch of stock is running out, see figure 16 which illustrates that as stock reaches the reorder point level an order will be placed, but depending on how much stock is used during the lead time determines the overall stockholding level.

Figure 16: Diagram illustrating reorder levels and lead times



Rushton et al (2006)

2.8 Summary of reasons for having inventory

The reasons for having inventory within the supply chain are complex, but from the business perspective it's essential that the inventory that it holds meets the needs of the business. Inventory should be held in stock for the shortest amount of time as possible to ensure that any costs associated with having inventory in a warehouse is minimised, however this does not mean that no inventory should be held just that what inventory is held is held for the benefit of meeting customer demands.

Having discussed how inventory should be managed, the next section will discuss how inventory flows through the supply chain.

2.9 Supply Chain

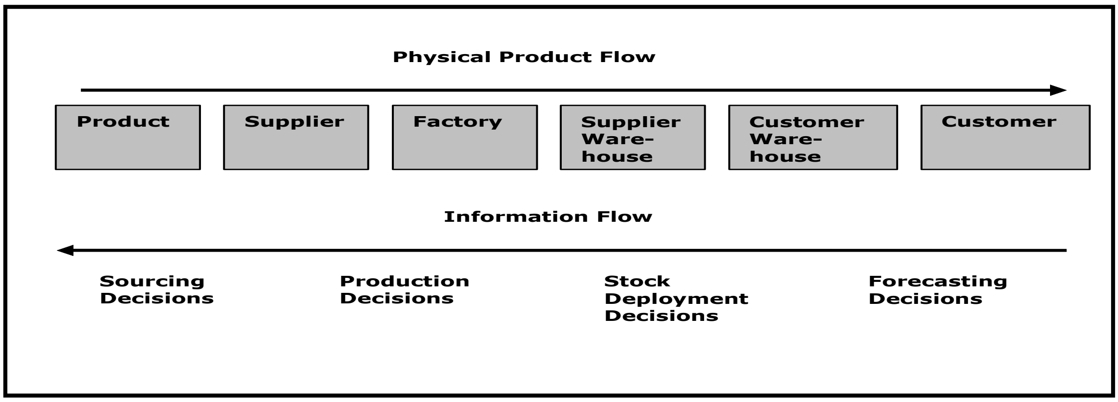
Supply Chain Management is defined as "the active management of supply chain activities and relationships in order to maximize customer value and achieve a sustainable competitive advantage. It represents a conscious effort by a firm or group of firms to develop and run supply chains in the most effective and efficient ways possible" (Bozarth & Handfield, 2008).

For any business it's essential that customer requirements are fulfilled. Slack et al (2001) summarise what supply chain management is by drawing together that it includes all stages in the flow of materials and information at the consideration of the final customer. The authors recognise that the following questions must be addressed "What level of quality, speed, dependability and flexibility do I need to develop in my part of the chain in order to satisfy the end customer?" For RRE the management of the supply chain is becoming ever more important as demand means that in certain areas of the supply chain capacity is nearly at full capacity. It is therefore vital that RRE ensures it is asking for the right goods to be produced in the volumes required to satisfy customer demands.

Customer demands are met through the coordination of materials and information flows throughout the supply chain. For supply chains to be successful, customers throughout the whole supply chain need to be reviewed. Often many companies only think about the requirements of the end-customer and therefore forget their own internal customers along the supply chain. If costs in a business are going to be managed its essential that a review of the whole supply chain is undertaken from raw materials, components, parts, tools, consumables and or services.

Having recognised the importance of the customer throughout the supply chain, organisations recognise how materials flow along the supply chain, but many fail to coordinate information flows that are also required to effectively manage the supply chain, see figure 17. Some organisations like Rolls-Royce are manufacturers and service providers at the same time as the company is responsible for the manufacture of approximately 30% of its goods and has its own overhaul bases. Unless information flows both ways along the supply chain difficulties will exist. With regards to inventory this may mean asking for the wrong items to be manufactured against what customers actually need, which will tie up valuable resources throughout the supply chain.

Figure 17: Flows in the Supply Chain



Adapted from Sherer (2005)

2.10 Summary of Literature Review

A number of different inventory models are available that depending on what the overall business objectives are. The systems have been developed over a number of years and should help an organisation like RRE to at least gain a better understanding of the overall costs involved in managing inventory through the supply chain. Much of the literature written about inventory addresses the same issues i.e. there is need to identify product costs, ensure inventory is held at the correct place in the supply chain, but what much of the literature ignores is how inventory is driven by organisational processes. Whilst authors such as Bonney (1994) note that holding stock is expensive and then demonstrate techniques and models such EOQ and ABC analysis there is little written about how to handle inventory across company boundaries. The importance of ERP systems across Rolls-Royce will be discussed in the next chapter.

Chapter 3 – Rolls-Royce Business Processes

3.1 Rolls-Royce Business Process Model

Having established that inventory needs to be managed, this section will outline how the Rolls-Royce business process model works as the model is an important part of inventory management throughout Rolls-Royce.

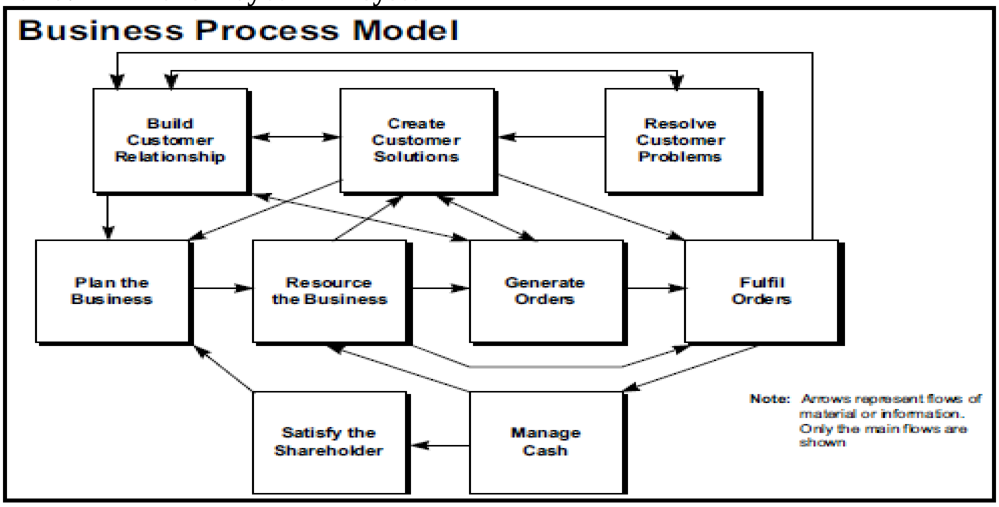
The business process model is in place create standardised approaches to business management across the whole business, and has been used since the implementation of an ERP system in the late 1990s. Whilst this drives a consistent approach it could also mean that best practices may be missed if they can not be applied using the business process model.

The business process model although designed around creating a standardised approach to the management of the organisation, it was developed when the majority of revenue throughout the business was provided by the Civil Aerospace CFBU. Ten years later on and although Civil Aerospace is still the largest contributor, the Defence Aerospace and Marine CFBUs are now not that far away from the size of Civil Aerospace and with the development of the Energy business at a fast pace this means that it is time to look at how inventory is managed to ensure that any processes used as a framework can be fully integrated into the different business units.

In the late 1990s, many organisations Rolls-Royce included recognised the supply chain was an integral part of their business. Rolls-Royce noted how the supply chain needed to be more flexible and responsive to changing market conditions.

For Rolls-Royce the organisation recognised that there was a need to re-engineer their business processes (Yusuf et al 2004). The aim was to integrate different processes by having standardised information applied throughout the business. This re-organisation for Rolls-Royce related to the introduction of a new IT system SAP which according to Yusuf et al (2004) requires a rigid business structure in order to be successful. Figure 18 provides a diagram showing how the business processes interact with each other. This process is still in use today.

Figure 18: Rolls-Royce ERP system



Data from Rolls-Royce (1998)

3.2 Introduction of SAP

The introduction of SAP led to many of the 1500 legacy IT systems being replaced with an integrated system. The structure which was outlined earlier of having Supply Chain Units and Customer Facing Business Units was put in place. The SCUs formed the manufacturing support for producing the product required by the CFBU. In turn, the CFBU had responsibility for marketing and selling within their individual segments e.g. Energy. Above the CFBU and SCU structure was a Group Executive which controlled the whole business and directed the overall direction of the organisation. Within the new organisational structure the company identified a number of business processes that are required to support the business.

Having introduced SAP into the business and altered the business structure, Rolls-Royce believed it had found the perfect system to improve its business. The next section identifies how ERP systems have evolved from other business process systems by undertaking a literature review.

3.3 Planning Systems

Since the 1960s manufacturing organisations have used a variety of different systems to plan their requirements. In recent years many of these older legacy systems have been replaced by Enterprise Resource Planning (ERP) systems that support all an organisations different process requirements. The next section will review how systems have evolved in today's ERP systems.

3.3.1 Material Requirements Planning (MRP)

Wallace & Kremzer (2001) believe it was the 1960s that ERP began life as Material Requirements Planning (MRP). They refer to the definition by APICS that says MRP is "A set of techniques that uses bill of material data, inventory data, and the master production schedule to calculate requirements for materials. It makes recommendations to release replenishment orders for material." MRP links inventory within the supply chain systems and integrates this data information with sales and financial operations of the organisation.

The aim of the MRP system is to ensure that parts are not produced until a demand requirement in the system exists, and this is done by integrating all the different bits of information into a coherent plan. This view is supported by Benton & Shin (1998) who say that MRP systems are designed to generate accurate inventory data that enables the business to plan the right order quantities at the right time to satisfy demand requirements.

McDonald (2009) acknowledges the use of technology in the MRP systems and says the system is a super computer that is able to provide output data based on selected criteria that are input into the system. McDonald also recognises the importance of having accurate data contained within the system. If you input poor quality data then the results may be far from what was envisaged. Many companies are still struggling to recognise the importance of accuracy in their production systems, which is possibly a result of transferring data from legacy systems where many defaults were usually input.

Table 9 illustrates the advantages of an MRP system over traditional techniques to manage inventory as identified by Wild (2002).

Table 9: Inventory Management Techniques

Inventory Level System	Material Requirements Planning
• Treats each part individually	• Deals with structure
• Depends on demand history	• Looks at future requirements
• Assumes average	• Handles erratic demands
• Aims to keep stock levels up	• Holds stock only to cover demand requirements
• Priorities inflexible	• Sensitive to priority changes
• Runs itself	• Needs management

Wild (2002)

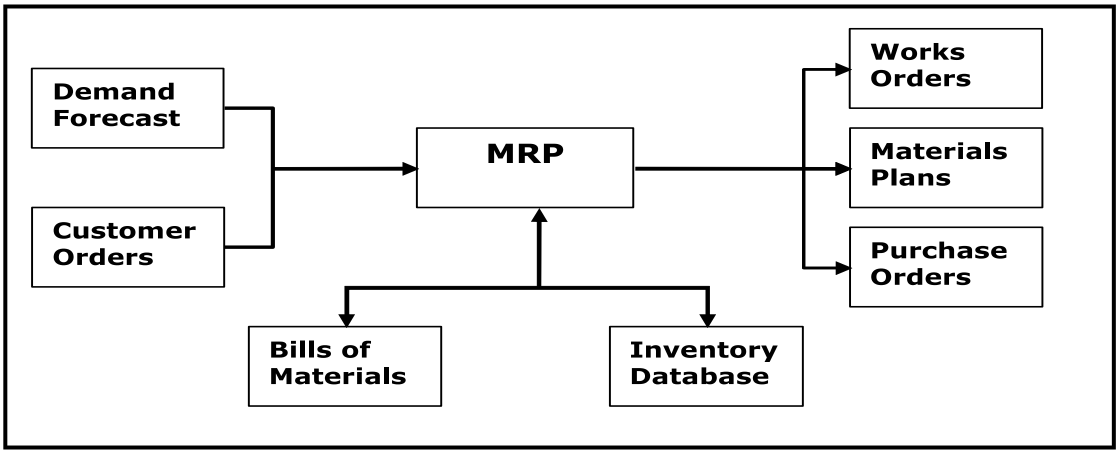
3.3.1.1 How does the MRP system work?

Having established the basis of what MRP is, this section provides a summary of how the system actually worked.

The MRP system either reads a physical customer order, forecasts orders, the master production schedule, or a combination of these. The system processes the data through the product bills of materials which generates the demand for products as well as demand requirements for raw materials. Having mentioned previously for MRP to work it needs accurate data information especially inventory data such as number of completed items currently held, work-in-progress as well as parts on order.

MRP will generate new planned releases every time it is generated. The system will amend delivery dates and quantities based on the latest demand requirements information contained in the system. Once an order in the system is changed to firm be either the computer or a planner, MRP will not change dates or quantities, but these can be manually changed. McDonald (2009) notes that action messages formed an integral part of the MRP system giving the planners suggestions to either pull forward or push back requirements. These so called exception messages provide valuable information to ensure that supply and demand requirements are balanced as a failure to act will either cause excess or shortage of product. Figure 19 illustrates how the MRP system works.

Figure 19: An MRP system



From Mangan et al (2008)

McDonald (2009) mentions that Oliver Wright, who developed MRP believed he had discovered the perfect process to eliminate shortage and control issues with regards to inventory management. However one of the biggest issues was that the system is not error proof and relies upon perfect information. If the information is not perfect the system is unable to plan properly, resulting in either excess or shortages.

The benefits of MRP to companies are varied and having analysed works by Ballou (1992), Yusuf (2004), Benton & Shin (1998), Zhao & Lee (1992), Slack et al (2001) the following are the key benefits of introducing an MRP system:

- Reduced inventory levels, combined with fewer shortages throughout the supply chain
- Reduction in excess inventory as parts are produced to a order requirement
- Improved customer service levels
- Improved productivity as orders are synchronised through the supply chain
- Improvement to supply and production schedules

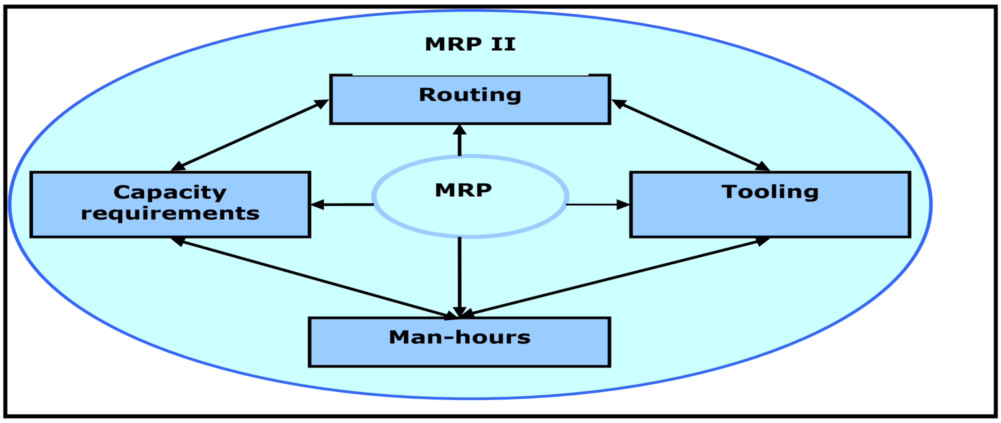
Whilst MRP can be seen to offer improvements to the business, there are also problems that need to be addressed. The authors outlined above mention the following problems:

- Data integrity issues – if there are any issues with inventory data for example this will result in the output data being manipulated
- System has standardised information such as lead times which in certain circumstances can cause problems, especially if lead times do vary significantly.
- As demand and supply fluctuates, every time the MRP system is run different results will be achieved

3.3.2 Manufacturing Resource Planning (MRPII)

In the 1970s Material Requirements Planning developed into Manufacturing Resource Planning (MRPII). Whilst MRP was primarily concerned with materials, MRPII integrated all aspects of the manufacturing process such as master scheduling, tooling, routings, capacity and manpower requirements. Brasen et al (2005) in their research demonstrate that MRPII is a subset of MRP, see figure 20.

Figure 20: Relationship between MRP & MRPII



From Brasen et al (2005)

Wallace & Kremzer (2001), using the APICS definition MRPII is "A method for the effective planning of all resources of a manufacturing company. It is made up of a variety of functions, each linked together: business planning, sales and operations planning, production planning, master production scheduling, material requirements planning, capacity requirements planning, and the execution support systems for capacity and material. Output from these systems is integrated with financial reports such as the business plan, purchase commitment report, shipping budget, and inventory projection in dollars."

MRPII begin with material requirements planning, which as highlighted previously provides the demand signal. MRPII creates a detailed production schedule that takes into account capacity constraints, e.g. machinery. The difference between MRP and MRPII is summarised by Johnson (1986) who states that the MRP system is a simple mathematical model, whilst MRPII is a complete management system.

Johnson's (1986) work illustrated that one of the main benefits of MRPII is that it tries to drive the business towards having zero inventory, assumes demand is not steady and is able to set priorities. By integrating information throughout the organisation management are able to take control.

Although MRPII was built on the foundations of MRP there have been a variety of criticisms regarding the system. Bozarth & Handfield (2008) note a phenomenon called MRP nervousness. This is caused because demand is driven through the system by top-level a material which creates subsequent demand requirements on lower-level materials. A small change in the top-level demand can have drastic effects further down the supply chain.

3.3.3 Enterprise Resource Planning

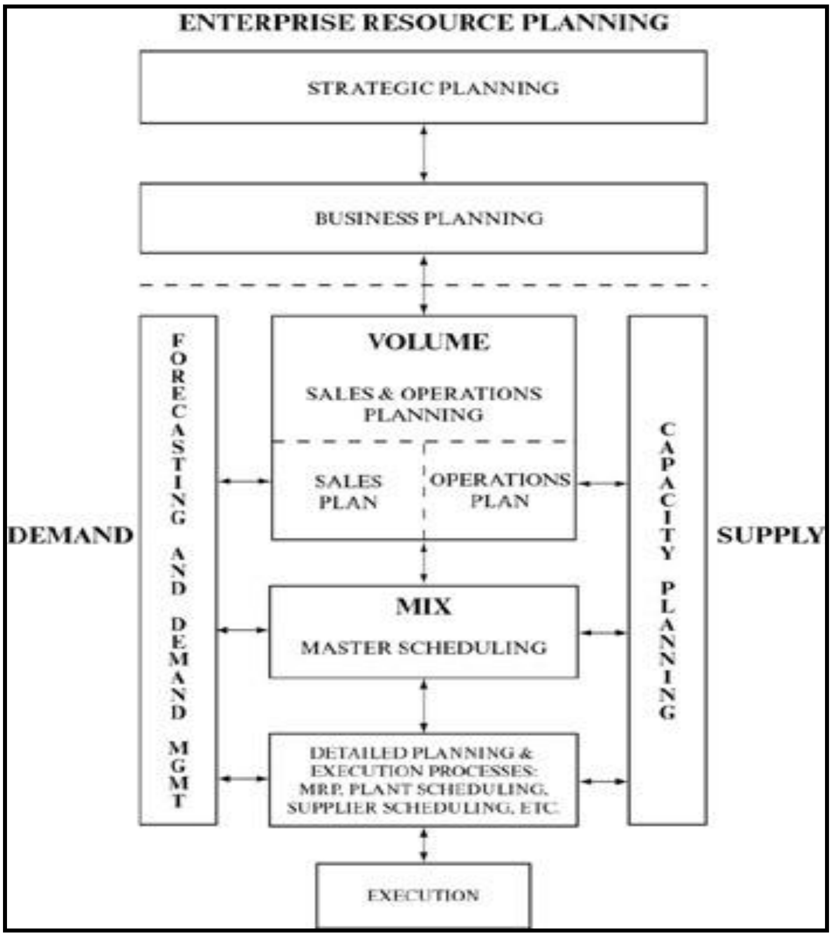
The most recent evolution has been the development of Enterprise Resource Planning systems. ERP systems differ from MRPII systems as it addresses technical and system requirements in a different manner (Adam & Sammon 2004). While MRPII focused on planning and scheduling of internal resources, the ERP system incorporates external resources into the equation. This is achieved by trying to plan and schedule supplier resources as well as the businesses own resources. Razi & Tam (2003) say ERP is "defined as a configurable information systems package that integrates information and information-based processes within and across corporate functional areas." Kashef et al (2001) define ERP as being set different applications that help to manage and automate the business. Bozarth & Handfield (2008) say ERP systems are "large, integrated, computer-based business transaction processing and reporting systems."

Underpinning ERP systems is a large database that provides information to all the different business applications that require the data. ERP systems incorporate all elements of the business from financial process, human resources, management, manufacturing, logistics and supply chain management. Figure 19 illustrates the interactions between the different areas of the enterprise (business).

Wallace & Kremzer summarise what ERP is about and its growth from earlier systems, such as MRP. "Enterprise Resource Planning is a direct outgrowth and extension of Manufacturing Resource Planning and, as such, includes all of MRP II's capabilities. ERP is more powerful in that it: a) applies a single set of resource planning tools across the entire enterprise, b) provides real-time integration of sales, operating, and financial data, and c) connects resource planning approaches to the extended supply chain of customers and suppliers.

Research by Adam & Sammon (2004) notes whereas MRP and MRPII are clearly defined, ERP does not have a clearly defined definition. Appendix 4 provides a chart of their research into the different definitions. All the definitions point to ERP systems as operating across your business by integrating business processes. Activities across the enterprise link customers and suppliers into a complete supply chain by coordinating sales, marketing, operations, logistics, purchasing, finance, product development, and human resources, see figure 21.

Figure 21: **Enterprise Resource Planning**



Wallace & Kremzer (2001)

Within Rolls-Royce, when ERP was being put in place the corporate information said of ERP "an amalgamation of a company's information systems designed to bind more closely a variety of company functions including human resources, inventories and financials while simultaneously linking the company to customers and vendors." This view is supported by most users of the SAP system utilised by Rolls-Royce, which according to Kashef et al (2001) is used by 20,000 different companies globally.

3.3.3.1 Advantages of ERP systems

With so many different companies using ERP systems, this section will identify the advantages of using such a system, and identify the key inventory management elements that are supported by such a system.

One of the primary advantages for a business in using an ERP system is that it is able to bring together all of the different business functions. Take Rolls-Royce for example, before the introduction of ERP the company utilised 1,500 legacy systems which meant the transfer of business information was difficult as they often ran on totally different systems. By integrating this information in a live system all the different business processes could see what was required of them.

3.3.3.2 Disadvantages of ERP systems

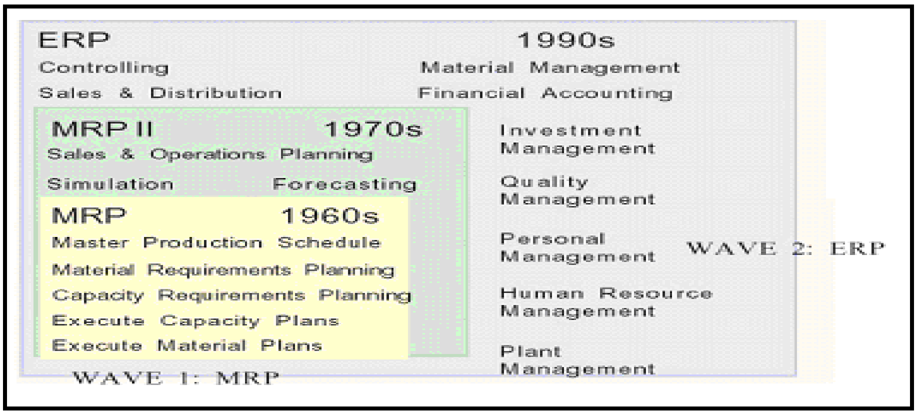
A disadvantage of ERP systems is that in most cases the organisational structure of your business is changed to suit the ERP system requirements, which is supported by Wisner et al (2009) and Gardiner et al (2002). Rolls-Royce when ERP was implemented had to change its business model to suit. Even today there are problems trying to get the requirements of different business amalgamated into the SAP system. For RRE this often means that requirements that would benefit the business are overlooked unless they can be applied across all CFBU plants.

A common problem with ERP systems is that the different parts of the business although has the ability to share common data are afraid of working with other departments. For example, the supply chain often criticises the purchasing department even though they have the common objective of procuring parts for customers. The supply chain may prefer small infrequent deliveries of parts, but if the buyer can obtain a discount for ordering large less frequent deliveries it is usually the buyers' argument that wins.

3.4 Evolution of ERP systems

Figure 22 illustrates how ERP systems have evolved since the 1960s. The diagram shows how as each system has evolved additional process activities can now be integrated. The benefits of having integrated systems are to share information across the organisation. The next section will detail how ERP has been applied within Rolls-Royce.

Figure 22: Evolution of ERP systems



Adapted from Adam & Sammon (2004)

3.5 ERP in Rolls-Royce

This section will discuss how ERP currently operates within Rolls-Royce. Currently Rolls-Royce utilises two ERP systems. SAP which is applied in the majority of businesses, but parts of the marine division utilise a system called BAAN but longer term the aim is to consolidate all operations into SAP.

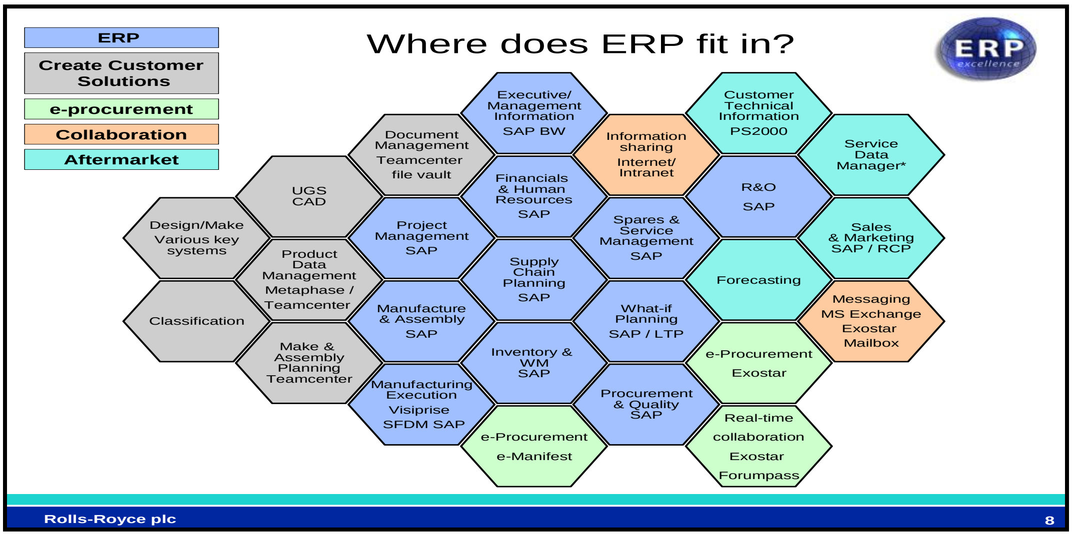
The SAP system is configured so that it operates as a push-type inventory system. This means that product is pushed through the system to meet anticipated demands that have forecasted by the CFBU plants, i.e. RRE. From an inventory perspective this does create problems as the system is unable to react quickly to demand changes so that effectively it is delivered as planned into the system. This means that the supply chain is unable to react to demand changes quickly and often results in the wrong kinds of stock being held. This creates tremendous burdens onto the whole supply chain, and if the wrong parts are being produced for stock, this could impact customer service levels.

3.5.1 ERP implementation

In the late 1990s' Rolls-Royce recognised that the 1500 legacy systems currently being used throughout the company could not be sustained. Whilst Rolls-Royce's legacy systems had developed using MRP and MRPII principles the development of ERP systems elsewhere was leaving the company behind.

As mentioned earlier, the implementation of ERP also recognised that Rolls-Royce needed to develop its business processes to ensure that they would fit within the new ERP software system SAP. As ERP was being implemented across the whole organisation the business brought together a number of representatives from the CFBU's and SCU's who were developed as 'Super Users' and 'Key Users', who became responsible for the training and implementation of SAP across their respective functions. The development included behavioural as well as transactional training requirements to ensure that the changes required to support ERP were successful. The initial role out started with a pilot in November 1999 and was fully completed by September 2000. Figure 23 below illustrates how ERP is applied in Rolls-Royce showing the different elements of the system and how they are applied across the organisation.

Figure 23: ERP in Rolls-Royce



Data from Rolls-Royce (2005)

Within the new operational structure of the business many important business activities were also changed to satisfy the requirements of the SAP system. ERP systems require accurate information if they are to be truly beneficial to the organisation. Yusuf et al (2004) noted in their research regarding ERP implementations how Rolls-Royce suffered from poor data integrity. This meant information that was being transferred out of Legacy systems had to be thoroughly checked when it was transferred across to SAP. This highlights more issues with legacy data systems, as Sainsbury's also suffered from major supply chain problems when they also transitioned from legacy systems to ERP style systems in their automated warehouse network.

3.5.2 ERP today in Rolls-Royce

As outlined earlier, a major constraint with the SAP system used by Rolls-Royce is the inability for the system to react quickly to demand changes. As the demands placed on the supply chain by RRE for example are estimated, if demand does not meet the expected supply requirements this creates surplus inventory, which is a cost to the business if it can not be sold, especially as the system operates as a MTS environment. This also impacts the frequency of stock turnover within the Rolls-Royce and RRE business respectively. The more inventory which is held in stock that does not move, the lower the inventory turnover ratio will be. Another problem common with ERP systems according to Waters (2003) is because it is linked across the whole supply chain, which means the information flows must be accurate as SAP is data driven. Poor data will result in either excess or shortages of inventory which impacts on the ability of the organisation to accurately plan future requirements.

Another problem apparent with the Rolls-Royce ERP system is that the approach used is very much a one-size fits all. This means that policies are applied throughout the organisation, even though OEM and aftermarket demand requirements are very different. This is often ignored by central Planners with the impact that any mistakes in the demand planning areas are often not resolved quickly enough, which means customer service levels are impacted.

From an inventory perspective, Rolls-Royce needs to ensure that it holds the right amount of inventory to meet all customer requirements, ensuring that the SAP system is configured to meet the different business requirements. The SAP system is configured essentially as being a push-type system in which the demand forecast/requirements acts as the production trigger. Whilst this works relatively well in an OEM environment with stable demand requirements, in the aftermarket with wide demand variations this causes inventory to build up. Also with finite capacity across many areas of the business, if inventory is being manufactured where it is not required this usually means a product that is required is not being manufactured. This is a major issue for Rolls-Royce and also means that inventory turnover is impacted because average stock levels are higher than they need to be.

Chapter 4 – Research structure

4.1 Research question introduction

The previous sections have reviewed the role of inventory management and business processes that are utilised within the ERP environment of Rolls-Royce. In the problem statement it was stated that RRE would like an investigation and evaluation made regarding the management of inventory within the RRE business as a way of helping it to improve the inventory turnover ration.

Initially when evaluating how to tackle the management of inventory in RRE, it was thought that one solution would be to hold inventory at lower levels in the supply chain, especially for high value parts. However some analysis conducted in the early stages of research suggested that much of the cost of parts is contained within the raw materials and even a £50,000 item may only be made of five parts that value wise equate to £45,000 therefore there is little value at holding inventory at lower levels. Also, RRE would have needed to consider the amount of inventory held elsewhere in the supply chain so from an inventory turnover perspective the benefits would be fairly small. During the initial stages of research, the application of TOC was also discussed, but the analysis indicated that Rolls-Royce to an extent was already pursuing improvement activities in trying to eliminate constraints through its process improvement activities; therefore research into this area was stopped.

Further research indicated that some of the reasons that inventory is not turning over as much as the management team would like is that some basis rules are not being followed which has led the research into establishing getting the basics right first.

The following research questions are to be investigated in order to propose possible solutions that will benefit RRE, this is based on the reasoning that current systems are not delivering the inventory turnover figure desired by RRE's management team. Investigations also indicate that some of the problems are caused because some of the basics of inventory management are not being applied, this will be explored in further detail during the analysis to the research questions identified below.

1. Review the current business process with regards to the management of inventory within the RRE aftermarket business: How does the information and material flow stream within the business process. This will involve analysing current systems in place and identifying whether the introduction of other processes such as introduction of ABC profiling could help to improve the way inventory is managed

2. Inventory by its nature ties up capital: How is it possible to reduce tied up capital in inventory and with what methods. This will investigate the impact of minimum order quantities in the RRE business and consider the use of MOQ/EOQ models into determining stock requirements.

3. Rolls-Royce uses the SAP system to deliver its ERP process, but as the system is set up generically across all different business areas does this result in poor inventory management. Can alterations be made to the SAP system so that RRE can improve the inventory carried whilst at the same time improving customer service requirements.

Chapter 5 – Analysis

This section will review the research questions identified in chapter 4 to determine what improvements are needed to improve the inventory turnover rates in RRE. Although the research questions are separated into three themes, the analysis will effectively answer them collectively as the processes such as ERP requirements are inter-linked.

5.1 Inventory management in RRE

Having identified that there is a reason for holding inventory, there is a requirement to manage that inventory. RRE aftermarket business carries approximately 10,000 live part numbers within the aftermarket environment, alongside another 5,000 live parts required in the production environment. The aftermarket part numbers are split into two categories:

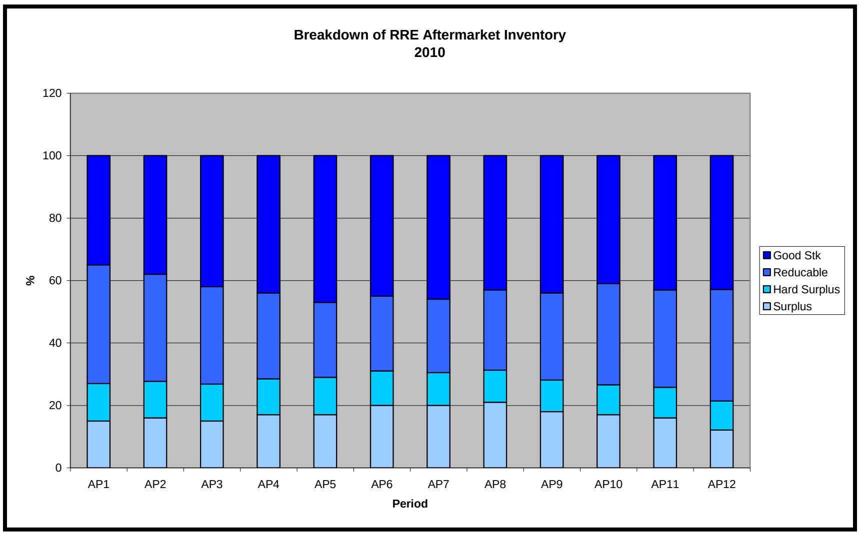
1. Gas turbine spares (GTS)
2. Package spares (PGS)

Due to the information available, the GTS parts will be critiqued although any solutions will also need to be robust enough and suitable for use within PGS and OEM sides of the RRE business.

With a large number of parts being carried, many of which are held as insurance type items, i.e. the potential is that the part will be required by a customer at some point in the future, but is not required generally for routine maintenance of the engine. Figure 24 provides a percentage breakdown of the stock carried which is broken down into the following inventory categories, based on stock holdings during 2010:

- Good – stock that will be used within three months
- Reducible – stock that wont be used within three months, but will be used within the horizon of the SAP system (7 years)
- Surplus – carries excess stock at the SAP horizon (7 years), but has at least some form of demand
- Hard surplus – materials which have no demand in the SAP system

Figure 24: Breakdown of RRE Aftermarket Inventory



The diagram clearly illustrates that if RRE wishes to improve inventory turnover then attention will need to be paid to increase the levels of stock in the 'Good Stock' category whilst at the same time reducing the levels of 'hard surplus' and 'surplus' materials that are carried.

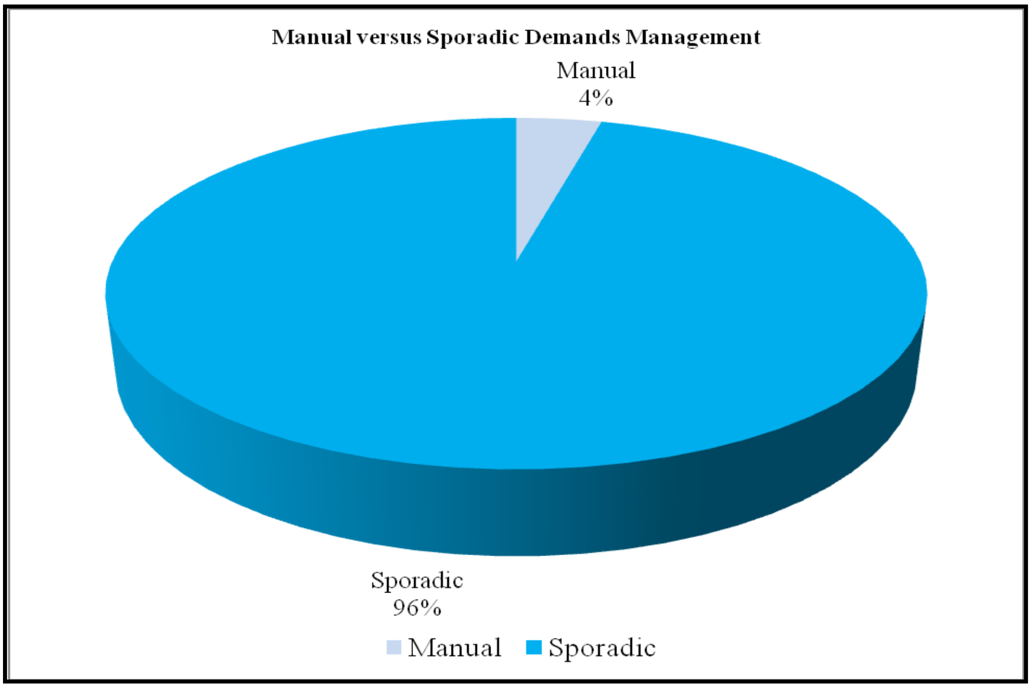
5.1.1 Current Practice – Demand Management

One of the biggest issues within RRE's aftermarket business is the ability to accurately plan future demand requirements, so that when a customer order is received stock will be available to meet the customer's expected delivery date. Relating back to Bianco's (2006) work on Wal-Mart's supply chain where information is readily available to ensure supply and demand is matched equally to ensure stores have stocks available to meet customer requirements. This basic management process of inventory needs to be controlled rigorously within RRE to ensure the right products are available to meet customer demands.

Currently forecasting demand requirements is carried out by two forecasters who carry out demand history forecasting, this means they forecast future demand requirements by assessing the historic demand pattern and using this information and local intelligence predict the future demand requirements. The SAP system calculates the following parameters, the Mean Order Size (MOS) and the mean Inter Arrival Times (IAT) between orders. The system is also able to generate variability of MOS and IAT so that where an order deviates significantly from normal patterns this does not impact the general forecast expected, i.e. it ensures the system does not react too quickly to unique events. Using all of this information a stock target is calculated so that this information can be cascaded through the supply chain to the SCUs so that when an order is received stock will be able in place to meet the delivery requirement.

Although demand requirements are forecasted, analysis of the overall number of aftermarket parts however indicates that the majority of parts are system forecasted with only a small percentage being manually adjusted by the actual forecasters, see figure 25.

Figure 25: Manual versus Sporadic Demands Management



5.1.2 Utilisation of ABC criteria

With 96% of parts being managed by sporadic forecasts there is a great opportunity to improve inventory management by generating a more reliable demand management process. Rolls-Royce has in place a process for managing the low value parts i.e. nuts, bolts and washers and these parts have been outsourced to a third-party provide called Pattonair for many years. The current 'C-Class' process employed by Rolls-Royce is that any item with a standard cost of less than £500 is generally outsourced, although in recent years that standard cost has been avoided and the company has decided to move any suppliers of low value parts via the third-party even when the overall standard price is greater than £500. RRE has over 2500 parts managed by Pattonair.

However within RRE this still leaves approximately 7500 parts to be managed by other means. If inventory turnover is to be improved which is one of the key drivers of RRE management, its essential to evaluate the current parts list so that those parts which deliver the greatest revenues are managed more comprehensively than those parts that are required to support the customer but that from a cost perspective perhaps do not need as much time spent on them.

From the research undertaken in previous chapters, one technique that could be applied within RRE is the use of ABC inventory classification. To carry out ABC analysis, the first step is to list all of the available products that the company has, the standard price (cost) of a single product and the number of units used in a given time period. To assess RRE sales during 2010 have been used. The cost of each product is then multiplied by the number of units used to generate annual expenditure. Once the annual expenditure of all products has been calculated, the products are then sorted from top to bottom in descending order of annual usage. The third step determines the cumulative percentage of the total annual cost provided by each product. Table 10 illustrates a worked example for a portfolio of 15 parts.

Table 10 : ABC Classification illustration

Material	**Product Rank by sales**	**Annual Sales (£m)**	**Cumulative Percent of total sales %**	**Cumulative Percent of total items**	**ABC classification**
RRX100	1	5050	33.7%	6.7%	A
RRX098	2	3400	56.3%	13.3%	
RRX101	3	1000	63.0%	20.0%	
RRX102	4	850	68.7%	26.7%	B
RRX085	5	825	74.2%	33.3%	
RRX088	6	705	78.9%	40.0%	
RRX065	7	700	83.5%	46.7%	
RRX123	8	600	87.5%	53.3%	C
RRX456	9	550	91.2%	60.0%	
RRX745	10	325	93.4%	66.7%	
RRX987	11	325	95.5%	73.3%	
RRX159	12	300	97.5%	80.0%	
RRX753	13	150	98.5%	86.7%	
RRX454	14	120	99.3%	93.3%	
RRX111	15	100	100.0%	100.0%	
		15000			

5.1.3 Using ABC in RRE

The above example demonstrates simply how the technique is applied; this section will show the affect when applied to RRE.

Currently SAP is configured so that information is applied in the same way to all parts regardless of overall spend. Whilst low value parts are recognised and characterised as 'C-Class' this still leaves the rest of the RRE portfolio to be managed. For these reasons, the analysis will assume that the low value parts that have already been outsourced and internally called 'C-Class' (2500 parts) will continue to be managed in this manner as this is business strategy.

The classification can be done in a number of different ways. Using the RRE data I have determined the classification surrounding the generation of sales revenue. Figure 26 and table 11 illustrates 80% of RRE's sales turnover is generated by just over 3% of the number of spare parts that can be supplied.

Figure 26: RRE ABC classification summary

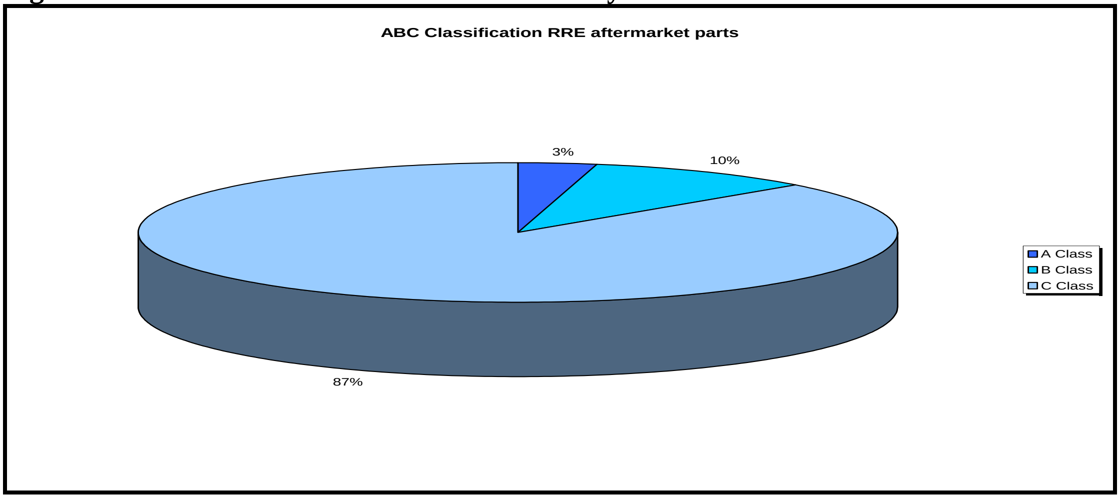


Table 11: Breakdown of RRE parts into ABC categories

Category	Number of Parts	% of sales	% of items
A	242	80%	3.2%
B	738	15%	9.8%
C	6520	5%	87%
Total	7500	100%	100%

From an inventory management and business perspective going forward the business needs to ensure that these 242 parts are always available to meet customer demand requirements. Using this information RRE needs to assess the overall stock targets that are associated with these products. The standard price of the A class items ranges from £10.12 to approx £250k. It is interesting to note that although the classic Rolls-Royce ‘C-Class’ parts were excluded from this analysis there are still a number of parts that could possibly be outsourced to Pattonair as they fall within the accepted ‘C-Class’ criteria. What the analysis demonstrates is that the management of inventory is only ever as robust as the processes in place to support. Of the 242 A class parts, 64 should be outsourced to be managed by Pattonair.

5.1.4 Management methods for different classes

Having categorised parts into A-B-C classes, the next step will be to determine the best process to manage parts going forward. The next section looks at how inventory costs are managed especially with regards to the management of order quantities which because of the large number of ‘C-Class’ items needs to be carefully executed to ensure capital is not tied up in the wrong products.

5.2 Review of inventory costs

From the ABC classification information carried out above, one of RRE’s biggest issues surrounds the inventory management process for those items that are required to support the aftermarket business, but are sold infrequently which is probably those items that the total quantity sold each year as it the most only one item, i.e. those items that are classified as ‘C-Class’.

Whilst the business needs to ensure that these items are available as and when a customer order is received, from a supply chain perspective items that are only required infrequently are sometimes difficult to manufacture cost effectively which means RRE needs to evaluate the impact of order quantities on its supply chain to ensure products are available to support the business but at the lowest cost possible to the business.

5.2.1 Current practice

Currently Rolls-Royce logistics policy for SAP, is that it’s configured to automatically order parts as single items. For many suppliers this is not cost effective and issues arise internally over how order sizes should be managed, especially where the supply chain wishes RRE to order minimum order quantities.

The following factors are listed within Rolls-Royce's logistics policy in how MOQ's should be managed:

- Maximising material availability
- Minimise cash spend
- Minimise obsolescence and inventory write down
- Share risk through the supply chain
- Minimise storage space
- Incentives suppliers to minimise MOQ impact
- Minimise unnecessary resource consumed in processing MOQ
- Reduce MOQ incidents by holding surplus at correct level - increasing responsiveness
- Highlight absolute cost of product to project & customer and inform decision making
- Have robust surplus management policy

Whilst RRE may wish to only stock items as required, in the instance if the annual demand requirement is one that is how much stock should be purchased by the supply chain, this may not necessarily be the most cost effective solution for the whole supply chain.

Raw material vendors often insist on a minimum order quantity for parts that are unique to Rolls-Royce supply either by process or material specification. From the raw materials vendor perspective they are usually unwilling to hold excess material as the vendor believes Rolls-Royce will not come back and take all of the raw material originally ordered. This is especially true, if the raw material can not be worked into anything else. Due to these issues, and with the growing importance of ensuring that Rolls-Royce is able to support the long product life cycles of RRE products, Rolls-Royce needs to evaluate how the supply chain is able to handle MOQ issues by developing solutions that support the business.

Having already established that inventory is known to be a cost to the business, as working capital tied up in inventory can not be used elsewhere. The liabilities concerned with not having the correct inventory also need to be evaluated. Current guidance is that the CFBU will by exception pay direct for the 'excess' raw material. More usually the expectation is that the material is held within the SCU or is amortised into the product cost to reduce the requirement for purchase orders being raised. In practice because of accounting principles and monitoring of inventory, there is often reluctance for the SCU to hold low level raw material. The MOQ on the raw material ends up being manufactured into the top-level part number and is transferred along the supply chain which leads to a build up of obsolete stock that eventually is disposed of through a disposition process.

Where parts are made into top-level part numbers this can then create additional problems for other areas of the supply chain. The excess has to be stored in a warehouse and the costs involved with storage of products are often ignored throughout the supply chain. It may therefore be prudent for Rolls-Royce to review and hold more raw materials at a lower level as the cost of writing off obsolete raw material will be lower than writing down finished goods inventory.

5.2.2 Managing MOQs

The following scenarios have been evaluated by RRE to determine the most cost effective way of handling MOQs within its supply chain.

In the following example there is a demand for 5 units, but the supply chain requires the production of 25 units with the raw material vendor. This type of example will happen frequently during the latter stages of the product life cycle where the MOQ exceeds overall requirements. The following options are to be evaluated to determine the most cost effective way of ensuring Rolls-Royce is able to satisfy customer requirements:

- Option 1 – MOQ cost of raw material batch is amortised into reduced actual quantity purchased
- Option 2 – MOQ of raw material is paid and delivered in full and all parts processed up through the supply chain to finished goods to be stored in the CFBU warehouse
- Option 3 – MOQ of raw materials is paid for and delivered in full, but only the quantity required at top level part is processed and delivered to CFBU, the remaining MOQ is held as raw material with inventory allowance provided

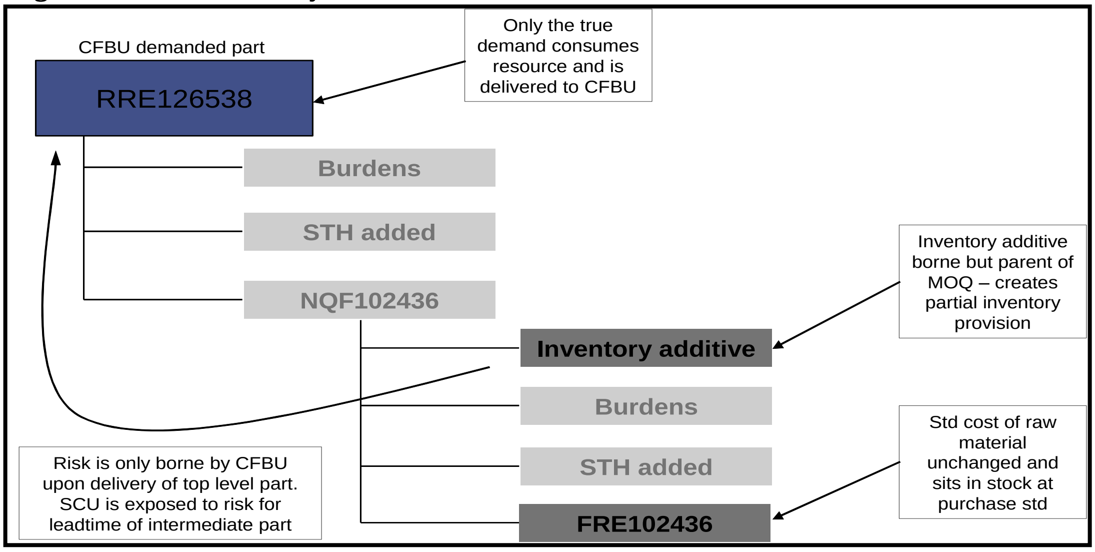
5.2.2.1 Inventory allowances

In the options outlined above, options 1 and 2 would continue to follow existing business practices, option 3 however would require a change to existing practices by the utilisation of an inventory allowance which is described below.

The inventory allowance in this example would be used to introduce the process of inventory postponement. The idea of the postponement process is to hold inventory at lower levels of manufacture. The advantages of utilising postponement strategy for the supply chain would be that capacity could be freed up. Time will not be spent on manufacturing parts with low demand. This freeing up of capacity would only benefit Rolls-Royce if the parts being manufactured use core components of faster moving lines. Also by holding inventory at lower levels in the supply chain, further value added activities are held back. This would therefore reduce the overall amount of obsolescence of completed products in the supply chain.

Figure 27 illustrates how the inventory allowance would be built into the standard cost of the parent part so an inventory allowance can be made for the raw materials held within the supply chain.

Figure 27: Inventory allowance



Whilst it may be seen from the Rolls-Royce perspective that postponement would bring financial benefits, it may mean that further down the supply chain vendors would be asked to hold speculative inventory, which they may be reluctant to do. This is one of the primary reasons where MOQs are applied in the supply chain, and for this reason why the idea of introducing an inventory allowance needs to be investigated.

By introducing an inventory allowance into the overall product costs, risk can be shared between the CFBU and SCU and/or vendors as appropriate. Analysis already undertaken by Rolls-Royce indicates that the introduction of an inventory allowance would improve the order behaviours of the customer plants, whilst simultaneously lowering the risk of suppliers of having unique Rolls-Royce material that can not be utilised.

5.2.3 Impact

In this illustration it is assumed that Rolls-Royce will not use the balance of material in the MOQ. In option 1 this means that all of the cost of the MOQ batch is absorbed by the Rolls-Royce order quantity, i.e. the residual inventory cost if fully absorbed. In option 2 as all of the MOQ is receipted into stock, all of the cost of the MOQ is absorbed by taking into stock the batch of 25 and manufacturing them into a finished part number. Option 3 assumes that only part of the residual cost is absorbed, 80% has been selected for this example. This results in a net Profit & Loss impact when the inventory is eventually written off. This will be offset in aggregate by those part numbers - the 20% - where a reorder effectively generates a profit by allowing a sale from stock with no cost incurred.

5.2.4 Costings

This section will review the associated costings of the example. The same scenario is used for each option: The CFBU plant has a demand requirement for 5 units, but the raw material MOQ is 25.

Table 12 provides the results of the costing exercise. As can be seen the overall outcome depends on a number of different factors. If the customer only ever demands quantity 5 then there is no cost difference between options 1 and 3, however if any subsequent orders are received then option 3 becomes the most cost effective option followed this time by option 2.

If a number of orders are received over time, option 1 is clearly not a cost effective solution and would not be pursued. Option 2 and 3 however have the same overall costs associated, but option 3 had the advantage of lower capital outlay in the first instance as value added activities only take place as and when parts are required.

Table 12: MOQ costings

	Option1	Option 2	Option 3
Scenario where MOQ exceeds customer requirement	**MOQ cost of raw material is amortised into actual qty purchased**	**MOQ of raw materials is paid for and delivered in full and all parts processed and delivered to CFBU**	**MOQ of raw material is delivered in full but only true demand delivered to CFBU with inventory allowance added**
Raw Material Cost per 1 unit	£500	£100	£100
Top Level part inventory allowance			£320
Manufacturing cost per 1 unit	£150	£150	£150
Top Level standard cost derived	£650	£250	£570
Inventory holding after demand satisfied	£0	£5,000	£2,000
Allowance	£0	£0	-£1,600
Net Inventory	£0	£5,000	£400
Cash spent for initial order	£3,250	£6,250	£3,250
Cash spent if reorder required	£3,250	£0	£750
Total Rolls-Royce P&L impact	£0	£3,750	-£1,700
Total cash for initial and reorder	£6,500	£6,250	£4,000

5.2.5 Advantages & Disadvantages

5.2.5.1 Option 1

Option 1 where the MOQ is paid in full with the costs associated being rolled into the raw material standard purchase price by the way of amortisation.

The benefits of this option are that the process is relatively simple and straightforward to follow as the standard prices will only need to be amended once when an order is placed. As no surplus material is retained by the supply chain there are no issues with storage and handling costs and there would be no requirement for the finished part number to have provisions applied.

Disadvantages from option 1 are that there is an increased level of risk is any subsequent orders are received.

5.2.5.2 Option 2

Option 2 is where the MOQ is paid and material delivered and manufactured into the top level part number required.

The benefits for option 2 are associated with any repeat orders being received as stock will be readily available to fulfil any future demand requirements. From a systems perspective no changes to the SAP system would be required as standard prices would be applied.

The disadvantages from option 2 are cost related. As it is unknown whether all of the stock is required there is a large capital outlay required to purchase parts that potentially have no demand. From a supply chain perspective this option also means that capacity and resources are being utilised when not required. The excess product will also need to be stored in a warehouse which means additional costs may also need to be fully accounted for. Longer term is the stock is not utilised it will require to be provisioned for which will have an impact on the profit and loss account if materials are subsequently deemed to be obsolete.

5.2.5.3 Option 3

Option 3 is where an inventory allowance is provided for to enable goods to be hold at lower levels of WIP.

A benefit of option 3 is that it ensures parts are only manufactured into the finished part number as and when required. This means that capacity can be better utilised across the organisation. The costs associated with the part can be managed by the utilisation of the allowance which can be built into the SAP system.

A disadvantage of option 3 is that the WIP will still require storage as per option 2. These costs need to be carefully accounted for to ensure cost effectiveness of the overall solution. There is the potential that by holding products at lower levels in the supply chain that the true overall costs are not necessarily recognised especially by the CFBU plants, in this case RRE as the value of lower level inventory is held by the SCU. Concern is also needed to determine the actual costs of the goods that should be held at lower levels. Analysis of a Rotatives part, that is held in the CFBU plant at a cost of £60k approx shows that the combined cost of the lower level assemblies is nearly £55k so the overall value add to make a completed item is £5k, although this depends on how much lower level WIP is held based on lead times to manufacture.

In this example, option 3 would be the preferred solution to be used as it provides the lowest overall cost where demand is relatively small compared to the MOQ. However if demand increases such that there is less difference between customer demand and the MOQ then option 2 could also be used.

From the way inventory turnover is calculated option 3 for RRE is always going to be the preferred solution as the CFBU plant does not the value of lower level WIP. A note of caution is that for Rolls-Royce the inventory to an extent is still being held within the supply chain. This would need further evaluation to determine the true overall costs, as some simple analysis of a Rotatives part valued at £65k showed the lower level assembly parts equated to a value of £60k which is what would be held at the lower level, therefore the overall cost benefits may not appear as great as expected.

5.2.6 How to apply MOQ

Having provided a note of caution, if MOQ policy was going to change the greatest impact would be on those parts where the lower level assembly items as a percentage are significantly smaller than the overall cost of the completed items. This means the technique would generally apply to either ‘A-Class’ or ‘B-Class’ categories where the value of standard prices is likely to be greater than those in the ‘C-Class’ category.

By using MOQs to reduce the overall levels of inventory in RRE, this would improve inventory turnover as long as sales are maintained at current levels as overall stock holdings would be lower than currently. The other possible advantage of holding stock at a lower level is that the capacity provided back to the manufacturing cells should reduce arrear levels within the company, which in turn should mean that any changes in demand could be better met. This leads into the final research question regarding lead-times which are another reason of why stock turnover is poor in comparison to the OEM environment.

5.3 Implementation

As RRE wishes to improve the turnover of inventory then the business will need to ensure that the issues identified and discussed through the research questions can be implemented into the business. An important note however that unless changes are made that are supported by Rolls-Royce's ERP systems then any changes could potentially cause issues elsewhere in the supply chain, which although RRE may show an improvement in its inventory turnover, unless this is reciprocated throughout Rolls-Royce the changes will not be supported.

The categorisation of stock into 'A-Class', 'B-Class' and 'C-Class' is a relatively straightforward process to introduce. It is the results of how stocks are then managed going forward that will actually drive the improvements in inventory turnover. Due to the large number of parts that RRE has to provide for, it's important to integrate the categorisation into the SAP system. Currently the ABC indicators in the SAP system are used for a variety of different purposes. 'C-Class' items outsourced to Pattonair as previously described. 'B-Class' parts are used to identify 'range-parts', these are generally spacers which although every engine will require a space the actual spacer size is dependent on a number of other factors, so the whole range is stocked, quantities being based on consumption. Finally, 'A-Class' items are classified as critical items on the actual engine. This means that any changes required by RRE by using classification would need to be considered by Rolls-Royce as a complete business.

With 80% of revenues being generated by less than 250 parts the 'A-Class' materials these are the parts that really need to flow through the system, indeed Ballou (1992) says 'A-Class' parts should be called the 'fast-movers', 'B-Class' parts 'medium movers' and 'C-Class' parts 'slow movers'. By categorising the stock, RRE then needs to apply some form of service level that can be associated with the category. Figure x in section 5.1 illustrated that of the current stock held within the RRE aftermarket business approximately 40% of the stock is likely to be used within the next three months; of the remaining 60%, nearly 20% is not likely to be used within the next 7 years which is the SAP horizon, indeed nearly 10% is unlikely ever to be used.

5.3.1 Managing ‘A-Class’ materials

The first step will be to drive improvements in having a higher percentage of the stock carried that can be used within the next three months. Certainly all of the ‘A-Class’ materials should operate as a just-in-time basis, i.e. they are delivered to meet the expected customer delivery date, although ensuring that all required activities in regards to quality and warehousing can be completed. By having these items flow through the supply chain the amount of capital that is tied up in inventory could be reduced.

It’s also important to accurately predict requirements for ‘A-Class’ items, which is why there is a need for a good understanding of your overall customer requirements. One of RRE’s problems is the lead times associated with parts can be anything in excess of one year or more, but it is difficult to accurately predict requirements this far ahead. Due to these reasons the supply chain is often making goods in advance of requirements based on the information fed into the SAP system. For ‘A-Class’ items, it maybe more cost effective for Rolls-Royce overall to reduce the planning time fences in SAP so that they are more aligned with meeting demand rather than material input requirements. As the RRE business can accurately predict demand requirements for at least 90 days (3 months) having time fences in excess of three months will actually cause more instability in the supply chain. The goods involved are fast moving products that are revenue generating, yet often the supply chain says it needs more information to be able to plan. Whilst it is a valid question and one in which further research should be undertaken, to establish what are the long lead time components within the manufacturing environment and perhaps these items should be held as lower level assemblies further down the supply chain, so it is able to react to demands.

5.3.2 Managing ‘B-Class’ materials

The ‘B-Class’ items are those that do not generate the same levels of revenues at the ‘A-Class’ items, but will generate a sizeable amount of revenue so in terms of management it is unlikely that they will have predictable demands compared to ‘A-Class’ items. This means these are the items that are likely to be stocked by the utilisation of some form of stock target which should be based on demand history calculations. ‘B-Class’ items should also be evaluated using the EOQ formulas discussed previously to ensure the optimum levels of inventory are maintained in the supply chain, whilst ensuring that customer service is not impacted.

By utilising demand history and EOQ data, the amount of inventory held in stock for ‘B-Class’ items will be reduced. Within RRE, ‘B-Class’ items make up a substantial element of the reducible inventory, i.e. it will all be consumed within the SAP horizon but actually usage can not be confirmed.

To implement, the ‘B-Class’ strategy a complete overview of demand history and EOQ data will be required to set the inventory levels correctly.

5.3.3 Managing ‘C-Class’ materials

The ‘C-Class’ items by default are the lower value items, however although from a revenue perspective they do not generate large amounts of revenue they are still required by customers. Indeed, when an engine is being overhauled the overhaul can just as likely be stopped by a missing nut and bolt valued at less than £1 as it can be stopped by a missing shaft valued at £50k. These ‘C-Class’ items therefore need stock levels to be set based on demand history and EOQ data to ensure stock levels are kept to a sensible level. Due to the lower cost prices of these items, the stock targets can be set higher than you would want on an ‘A-Class’ or ‘B-Class’ item as the overall impact on inventory and therefore inventory turnover will be less.

Whilst rules can be set for the different classes, there are still a substantial number of parts in the RRE supply chain that need to be managed in a different manner. These are classed as insurance type items, with very unpredictable demand requirements, but costs involved can be high. An insurance item is likely to be an expensive item of at least £20k so can add substantially to the overall levels of stock held, but because of infrequent use cost of goods sold on these items are less so inventory turnover rates will be lower.

5.3.4 Management of insurance type items

Due to the costs involved for storing stock within RRE’s own supply chain, typically it is assumed that inventory costs approximately 7-10% of its standard price value each year. Items that are held as insurance items may not move for five or more years. If this material could be outsourced to a third-party operator such that it is readily available to meet any demand requirements but would not actually sit on the books of RRE this would help to improve the inventory turnover figures. Careful consideration would be needed especially from a financial perspective to ensure materials are fully provisioned as per current business rules, i.e. there have been no sales or receipts for at least two years so get financially provisioned.

Disposal of materials is a last resort for any business, and with the typical life span of an RRE engine being approximately 30 years, its worthwhile ensuring material is disposed of from RRE's books, is still available. This is practiced today, RRE currently disposes of its hard surplus materials to a third-party operator who stores the stock on its behalf, and receives a percentage of any future sales. Financially this is an attractive proposition for both companies concerned, and consideration should therefore be given to utilising similar methods for some of the slower moving 'B-Class' and 'C-Class' items that will have been identified through the ABC classification process.

The utilisation of third-party providers for managing RRE inventory is already in place. The majority of surplus materials are not physically disposed off, but are sent to a third-party company who looks after the stock on behalf of Rolls-Royce and then receives a financial reward for any sales generated. This process could be adopted to manage slow moving insurance type items, so that stock is readily available if required but the physical inventory does not sit on the books of RRE.

Due to the sensitive nature of what is outsourced and to whom, it can be safely assumed that the 'hard surplus' inventory would be outsourced and of the remaining surplus inventory the majority of what is held for insurance items could also be outsourced. The remaining stock that would be held on the books of RRE would improve the inventory turns to around 5.5, so additional work will still be required to get to RRE management figure of 6.

5.4 Analysis – ERP requirements

Whilst the introduction of ABC classification could easily be implemented within Rolls-Royce's ERP structure without creating any disruption, the changes to MOQ policy would need to be carefully evaluated by the organisations Centre of Competence to ensure that if options 2 or 3 were selected how this fits, with current business processes. If this is the way that RRE wishes to move towards then the management team will need influence the changes required to current systems. Whenever change is required to inventory management systems, it's essential that any changes are costed throughout the supply chain. There is no business benefit to Rolls-Royce plc if a cost saving in RRE is offset by increased costs elsewhere. This is often forgotten any many organisations, and even within Rolls-Royce claims are often made that one area of the organisation has reduced costs, but has failed to recognise their savings is another areas cots.

Chapter 6 – Conclusions & Recommendations

This final chapter summarises the key findings of the research and shows how they have accomplished the initial research aim.

The aim of dissertation was,

“to evaluate how inventory is currently managed; review inventory theories to provide recommendations that RRE can use to improve inventory turnover.”

6.1 How is inventory currently managed?

Inventory throughout Rolls-Royce is managed as an ERP process, RRE and its aftermarket business therefore has to utilise processes that are designed to be used across Rolls-Royces’ businesses.

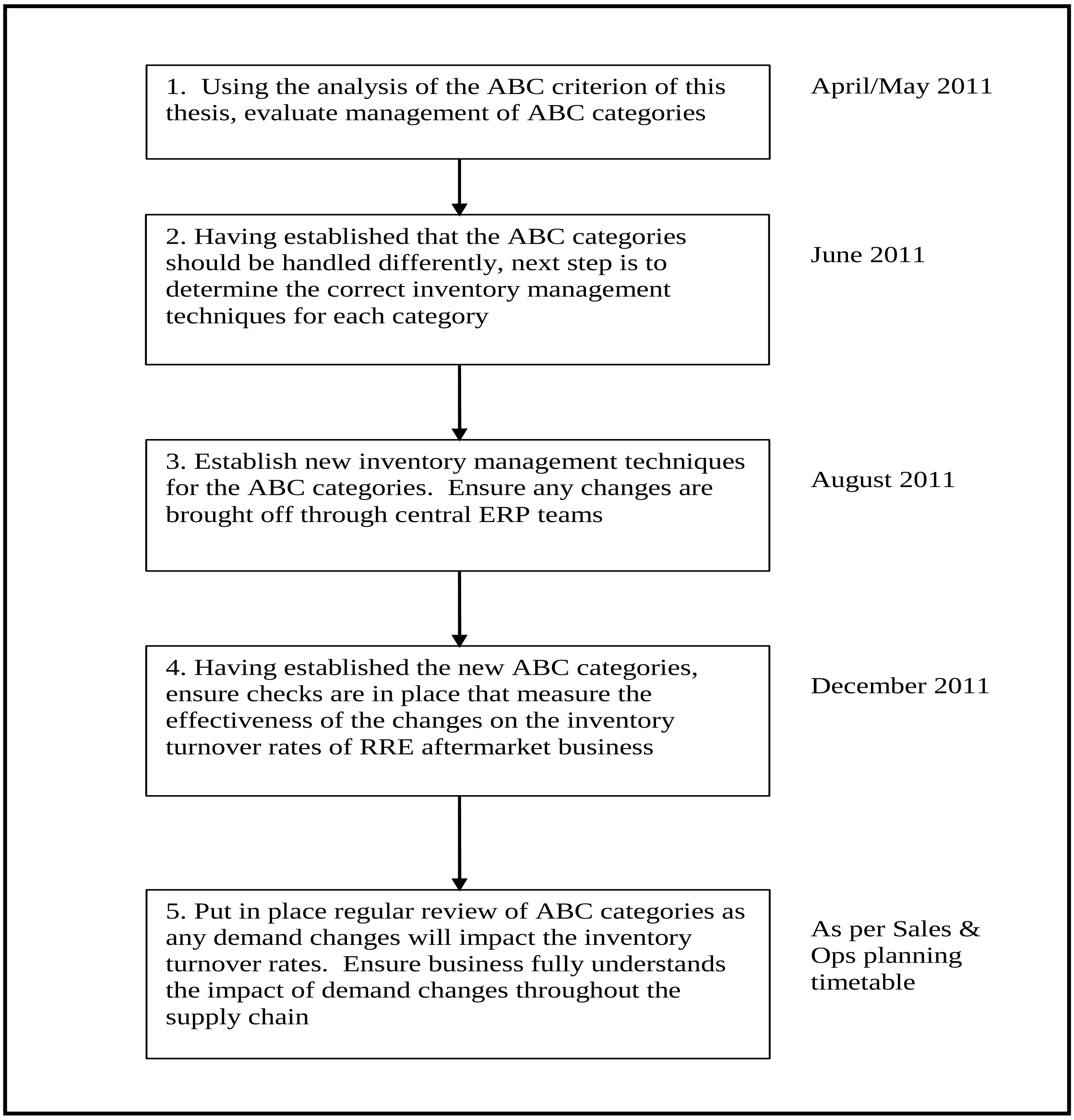
As mentioned in the introduction Energy aftermarket inventory is currently planned by two forecasters who are responsible and accountable for the management of a portfolio of approximately 10,000 live parts. It’s also worth noting that an Energy gas turbine can have a lifespan of greater than 30 years, which is considerably longer than the lifecycle of an aerospace gas turbine. Although the forecasters utilise the same business processes that are used elsewhere in Rolls-Royce the analysis of RRE indicates that more time and consideration is spent on assessing the inventory on the parts that generate the greatest revenue for the business.

If RRE is to meet its intended goal of improving inventory turnover, then the first steps will be to employ some basic inventory management techniques. The management of inventory in a manufacturing led organisation like Rolls-Royce is compounded by the use of the powerful SAP ERP system. As the SAP system is a push type system which requires stability this causes problems in the aftermarket business where demand requirements fluctuate. In an ideal world changes to the SAP would be required to improve its ability to handle aftermarket requirements, but considering that the existing systems and processes need to be used, RRE needs to improve the forecast management of its parts. To assist the application of the ABC process would provide improved levels of information on which parts need to be carefully controlled as they generate the highest levels of revenue.

6.2 Implementation of ABC analysis

Having recognised that RRE needs to improve the management of inventory, this section will determine the steps required to help improve the turnover of inventory in the RRE aftermarket business. Figure 28 provides a process chart that will help to move the RRE aftermarket business forward in its desire to help improve inventory turnover.

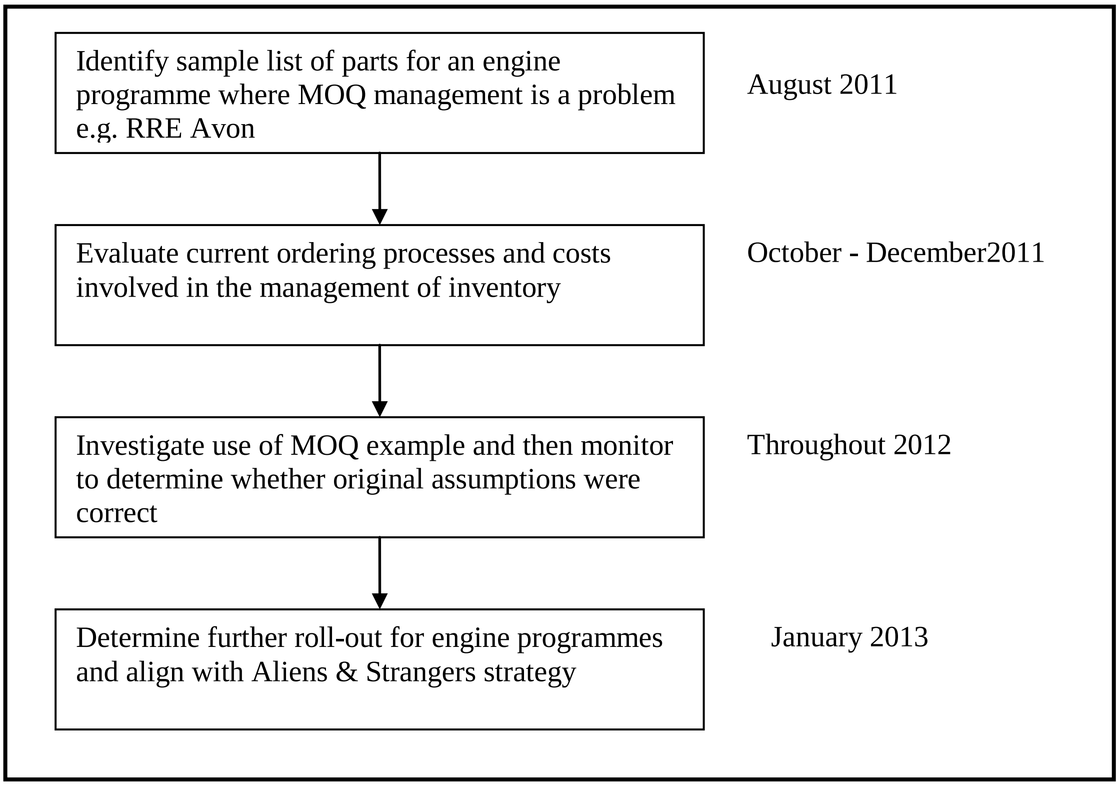
Figure 28: Implementation ABC analysis



6.3 Implementation of MOQs

Implementation of MOQs would need to be done in conjunction with the Aliens and Strangers parts category process that is already managed through the PPES SCU group. The roll out of this programme would be slower as it will need to be managed in conjunction with other business strategies, so time would be required to get this activity brought off by the supply chain. Figure 29 provides an illustration of expected guidelines for implementing the MOQ solution.

Figure 29: MOQ implementation summary

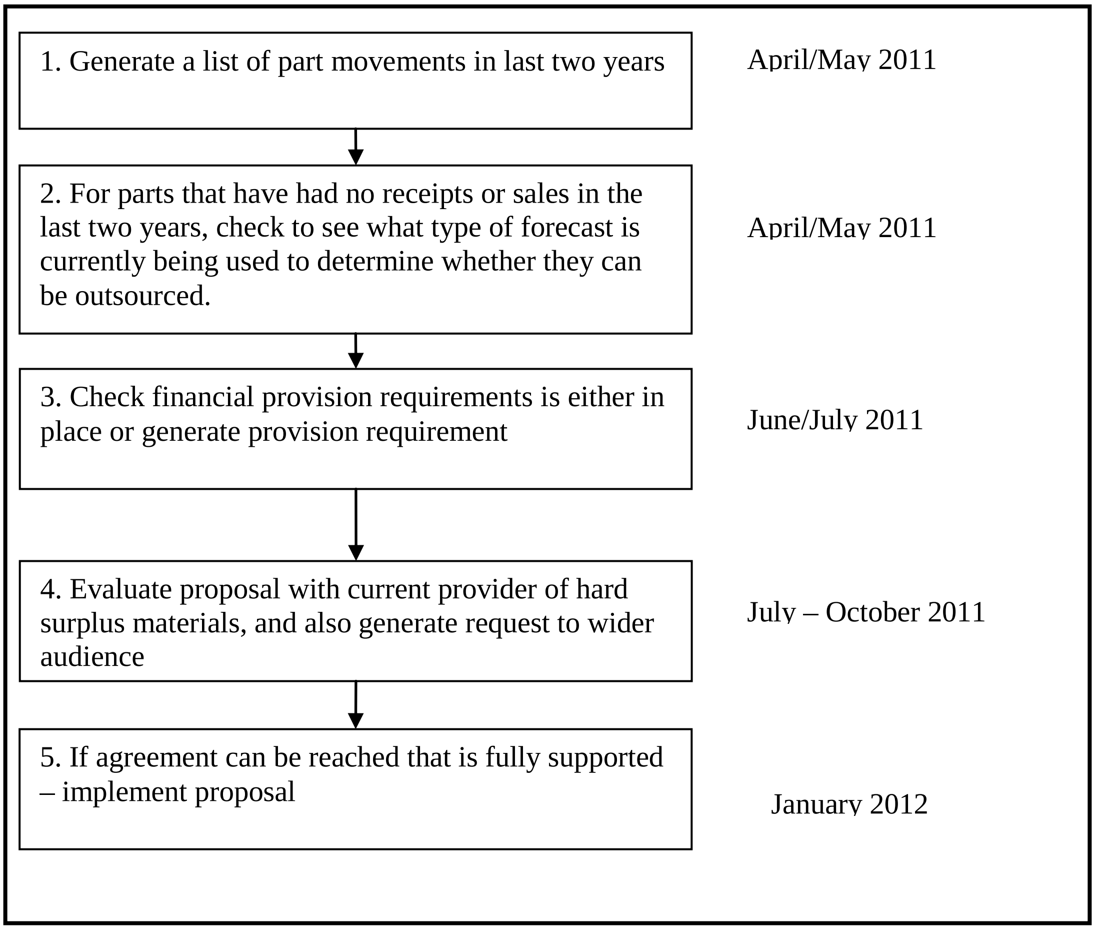


6.4 Outsourcing of Insurance Type Items

The need to carry inventory to maintain customer service levels is an important consideration for RRE, but problems arise where these materials are held but are only sold very infrequently say once every two or more years.

Ideally, from RRE’s perspective you would only want to receive these items into stock as and when orders are received. However, due to the lead times involved this is not practical in the way Rolls-Royce currently configures its SAP and this means that the stock is held as a finished item (because the costs of the raw material components is not that much less than the completed part). So whilst there may be a requirement for this stock in the future, there is no way of forecasting accurately when the stock will be required. To help improve the inventory turnover rates, insurance items that have not sold in more than two years could be outsourced to a third part provider. This ensures stock is available as a customer order is received, but does not financially sit on the books of RRE. Figure 30 provides a summary of how RRE could implement the changes to insurance type items.

Figure 30: Implement outsourcing of insurance items



6.5 Benefits

Of the three activities outlined above, the implementation of ABC categorisation and outsourcing of insurance type items should be relatively straightforward for the management of RRE to implement. The overall inventory reduction required is approximately £30m of which the outsourcing activity would clear at least £10m worth of inventory which would improve the inventory turnover rate to 4.5. By having A-class items operating on just-in-time and B-Class items with a complete demand review to set inventory target levels this would aim to reduce the stock holdings on these categories by approximately £15m, although more detailed analysis would be required to actually quantify any business benefits this would improve stock turnover rates to around 5.5 so some additional activities will be required to fulfil RRE's aims of having inventory turnover to 6.0 times per year.

6.6 Summary

This section will demonstrate that the three questions outlined in chapter four have been answered.

RRE currently abides by Rolls-Royce's business processes for the management of inventory. Forecasting, Demand and Supply management systems are utilised. The introduction of ABC inventory management, would allow RRE to ensure that inventory is more effectively managed by having different processes for different categories of goods. This would benefit RRE by ensuring it has the correct levels of inventory to support different categories but would also fit in with existing ERP process and behaviours. The only changes maybe how the different categories would be managed.

Having identified that inventory ties up capital by demonstrating that MOQs in the RRE supply chain could be handled differently this would help to improve inventory turnover within the business as inventory could be handled differently during different stages of the product life-cycle. This also recognises that alternative ways to manage inventory will be required, and if RRE wants to improve inventory turnover then it must be able to utilise different strategies as outlined in using the ABC categories.

All of the solutions identified would involve changes to the SAP system to enable them to be integrated into the ERP system. Initial analysis indicates that the solutions could be supported by ERP processes, but further analysis and trials would be needed before any changes were implemented and this would be discussed in the next chapter.

Chapter 7 – Suggestions for further research

Having analysed the management of inventory in the RRE business, it has become clear that many of basic processes that are supposed to support the business in the ERP system are not being applied robustly across the different business areas of Rolls-Royce. This leads to excess inventory being built up on certain items, but where demand does change the ERP is not able to react quickly enough, which then generates a level of surplus inventory.

To overcome these problems, an overhaul of the SAP system maybe required because it is a powerful tool and there are numerous different operating models that could be applied. To do this however it would be envisaged that some form of simulation model could be developed to determine the best operating methods for the different categories of parts.

Currently, Rolls-Royce configure the SAP system effectively as a one size fits all approach, but going forward if Rolls-Royce and RRE are going to manage inventory more effectively then consideration should be given to operating the categories differently so that customer service levels are maintained, but the business does not waste valuable capital tied up in slow moving inventory.

From the research undertaken for this thesis, another area where further development is required is to improve material costing data across the supply chain. The MOQ example aimed to demonstrate how valuable having accurate cost data is when trying to determine whether to order in larger or smaller batches especially towards the end of the product life cycle, but this information could also be applied elsewhere. Rolls-Royce needs to better understand and manage cost information across its business to determine what levels of inventory should be carried and where they should be held.

By taking the research onto the next steps, Rolls-Royce should aim to become a world-class player in inventory and supply chain management. Whilst many academics look at companies like Dell and Wal-Mart for best practice in years to come they should be looking at Rolls-Royce.

Bibliography

Journals

Benton, W. & Shin, H. (1998) Manufacturing planning and control: The evolution of MRP and JIT integration. *European Journal of Operational Research*. 110 p411-440. [online]. Available at: http://www.sciencedirect.com as at 6th March 2011

Keebler, J. & Plank, R. (2009) Logistics performance measurement in the supply chain: a benchmark. *Benchmarking: An international journal*. 16 (6) p785-798, [online]. Available at http://www.emeraldinsight.com as at 31st March 2011.

Muzumdar, M., & Fontanella, J. (2006) The Secrets to S&OP Success. *Supply Chain Management Review*, 10, (3), p.34-41, [online].
Available at: http://web.ebscohost.com as at 6th February 2011

Sherer, S. (2005) From supply-chain management to value network advocacy: implications for e-supply chains. *Supply Chain Management: An International Journal*, 10, (2), p.77-83, [online].
Available at http://www.emeraldinsight.com as at 19th March 2011.

Watson, K., Blackstone, J., & Gardiner, S. (2007) The evolution of a management philosophy: The theory of constraints. *Journal of Operations Management*. 25, p387-402. [online]
Available at: http://www.sciencedirect.com as at 10th February 2011

Willemain, T., Smart, C., & Schwarz, H. (2004) A new approach to forecasting intermittent demand for service parts inventories. *International Journal of Forecasting*. 20, p375-387. [online]
Available at: http://www.sciencedirect.com as at 6th March 2011

Yusuf, Y., Gunasekaran, A., & Abthorpe, M. (2004) Enterprise information systems project implementation: A case study of ERP in Rolls-Royce. *International Journal of Production Economics*. 87, p251-266 [online]. Available at: http://www.sciencedirect.com as at 6th February 2011

Zhao, X., & Lee, T. (1992) Freezing the master production schedule for material requirements planning systems under demand uncertainty. *Journal of Operations Management.* 11, p185-205. [online]
Available at: http://www.sciencedirect.com as at 7th March 2011

Books

Ballou, R. (1992) Business Logistics Management, 4th Edition. New Jersey. Prentice-Hall Inc.
ISBN: 0-13-081262-5

Bianco, A. (2006) Wal*Mart: The Bully of Bentonville How the High Cost of Everyday Low Prices is Hurting America. New York. Doubleday Books
ISBN: 978-0-385-51357-9

Bozarth, C., & Handfield, R. (2008) Introduction to Operations and Supply Chain Management, 2nd Edition. New Jersey. Pearson Education Inc.
ISBN: 978-0-13-135426-5

Slack, N., Chambers, S., & Johnston, R. (2001) Operations Management, 3rd Edition. Harlow. Pearson Education Ltd.
ISBN: 0273-64657-5

Stock, J. & Lambert, D. (2001) Strategic Logistics Management, 4th Edition. London. McGraw-Hill.
ISBN: 0-256-13687-4

Walton, P., & Aerts, W. (2006) Global Financial Accounting and Reporting Principles and Analysis. London. Thomson Learning.
ISBN: 978-1-84480-265-4

E-Books

Adams, F., & Sammon, D. (2004) The Enterprise Resource Planning Decade: Lessons Learned and Issues for the Future. [e-book] IGI Publishing.
Available from <http://skillport.books24x7.com> as at 15th February 2011

Baudin, M. (2004) Lean Logistics: The Nuts and Bolts of Delivering Materials and Goods. [ebook] Productivity Press
Available from <http://skillport.books24x7.com> as at 29th March 2011

Brasen, S., Lamming, R., Bessant, J & Jones, P. (2005) Strategic Operations Management, 2nd edition. [ebook] Butterworth-Heinemann.
Available from <http://skillport.books24x7.com> as at 4th March 2011

Christopher, M. (2005). Logistics and Supply Chain Management. [ebook]. Pearson Education UK.
Available from:<http://lib.myilibrary.com?ID=60108> as at 14th March 2011

Goldsby, T., & Martichenko, R. (2005) Lean Six Sigma Logistics: Strategic Development for Operational Success. [ebook] J. Ross Publishing
Available from <http://skillport.books24x7.com> as at 29th March 2011

Hamilton, S., (2003) Maximizing Your ERP System: A Practical Guide for Managers. [e-book] McGraw-Hill.
Available from <http://skillport.books24x7.com> as at 6th February 2011

Levinson, W., (2007) Beyond the theory of constraints: How to eliminate variation and maximise capacity. [ebook] Productivity Press.
Available from <http://skillport.books24x7.com> as at 11th February 2011

Lowe, D. (2002) The Dictionary of Transport and Logistics. [ebook] Kogan Page.
Available from <http://skillport.books24x7.com> as at 14th March 2011.

Mangan, J., Lalwani, C., & Butcher, T. (2008) Global Logistics and Supply Chain Management. [ebook] John Wiley & Sons
Available from <http://skillport.books24x7.com> as at 28th February 2011

Muller, M. (2003) Essentials of Inventory Management. [ebook] AMACOM
Available from <http://skillport.books24x7.com> as at 28th March 2011

Muller, M., & Langenwalter, G. (2006) Fundamentals of Inventory Management and Control, 3rd edition. [ebook] Amacom

Available from <http://skillport.books24x7.com> as at 28th February 2011

Palmatier, G., & Crum, C. (2003) Enterprise Sales and Operations Planning: Synchronising Demand, Supply and Resources for Peak Performance. [ebook] J. Ross publishing.
Available from <http://skillport.books24x7.com> as at 24th February 2011

Rushton, A., Croucher, P., & Baker, P. (2006) A Handbook of Logistics and Distribution Management, 3rd edition. [ebook] Kogan Page.
Available from <http://skillport.books24x7.com> as at 1st March 2011

Sheldon, D. (2006) World Class Sales & Operations Planning: A Guide to Successful Implementation and Robust Execution. [ebook] J. Ross publishing.
Available from <http://skillport.books24x7.com> as at 24th February 2011

Viale, J. (1996) Basics of Inventory Management From Warehouse to Distribution Center. [ebook] Course Technology Crisp.
Available from <http://site.ebrary.com> as at 20th March 2011

Wallace, T., & Kremzar, M. (2001) ERP: Making it happen: The Implementers' Guide to Success with Enterprise Resource Planning. [ebook] John Wiley & Sons.
Available from <http://skillport.books24x7.com> as at 11th February 2011

Winston, W. (2011) Microsoft Excel 2010: Data Analysis for Business Modeling [ebook] Microsoft Press.
Available from <http://skillport.books24x7.com> as at 2nd April 2011

Other articles

Chen, Y., Li, K., & Liu, S. (2008) A Comparative Study on Multicriteria ABC Analysis in Inventory Management. Unknown article.

Harding, M. (2004) Calculating the carrying cost of Inventory.
Available from: http://www.ism.ws/files/Pubs/Proceedings/BCHarding.pdf Accessed 29th March 2011.

Annual Reports

Rolls-Royce 2010. Teamwork and Technology. London: Rolls-Royce plc. London: Rolls-Royce plc.
Available from: http://www.rolls-royce.com/reports/2010/ Accessed: 23rd March 2011.

Rolls-Royce, 2009. Delivering today, investing for the future, annual report, London: Rolls-Royce plc. London: Rolls-Royce plc.
Available from: http://www.rolls-royce.com/reports/2009/ Accessed: 23rd March 2011.

Rolls-Royce 2008. Technology creates global opportunities. London: Rolls-Royce plc.
Available from http://www.rolls-royce.com/reports/2008/ Accessed: 23rd March 2011.

Rolls-Royce 2007. A global business. London: Rolls-Royce plc. Available from http://www.rolls-royce.com/reports/2007/ Accessed: 23rd March 2011.

Rolls-Royce 2006. Opening. London: Rolls-Royce plc. Available from http://www.rolls-royce.com/reports/2006/ Accessed: 23rd March 2011.

Rolls-Royce 2005. Innovation + Integrity + Reliability London: Rolls-Royce plc. Available from http://www.rolls-royce.com/reports/2005/ Accessed: 23rd March 2011.

Rolls-Royce 2004. Our strategy for future success consists of five key elements… London: Rolls-Royce plc. http://www.rolls-royce.com/reports/2004/ Accessed: 23rd March 2011.

Rolls-Royce 2003. Creating value by investing in technology and capability once and using many times. London: Rolls-Royce plc.
Available from: http://www.rolls-royce.com/reports/2003/ Accessed: 23rd March 2011.

Rolls-Royce 2002 Annual Report 2002. London: Rolls-Royce plc.
Available from: http://www.rolls-royce.com/reports/2002/ Accessed: 23rd March 2011.

Rolls-Royce 2001. Annual Report 2001. London: Rolls-Royce plc.
Available from: http://www.rolls-royce.com/reports/2001/ Accessed: 23rd March 2011.

Other information

Rolls-Royce (1998). Enterprise Resource Planning a business perspective.

Appendices

Appendix 1: Extracted from 2010 Rolls-Royce Annual Report

Business review

Governance

Financial statements

OUR CONSISTENT STRATEGY

OUR CONSISTENT STRATEGY IS BASED ON FIVE KEY ELEMENTS

1

ADDRESS FOUR GLOBAL MARKETS

We are a leading producer of mission critical, integrated, power systems for the civil and defence aerospace, marine and energy markets.

Civil aerospace
Broadest engine range in the world

£4,919m
Underlying revenue 2010

Defence aerospace
Europe's biggest engine maker

£2,123m
Underlying revenue 2010

Marine
World-leading systems provider and integrator

£2,591m
Underlying revenue 2010

Energy
World leader in power for the oil and gas sector and a growing power generation presence

£1,233m
Underlying revenue 2010

2

INVEST IN TECHNOLOGY INFRASTRUCTURE AND CAPABILITY

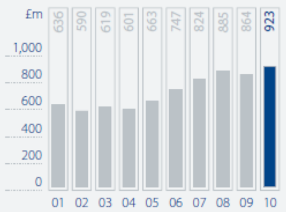
Over the past five years, we have invested £4.2 billion in R&D. We invest substantially in employee development and, in 2010, we invested £361 million in capital projects.

A strong record of investment in research and development
We invest in world-class, cost-effective technology in order to develop products that add value for our customers, improve efficiency and reduce environmental impact.

Investment in research and development during 2010

£923m

GROSS RESEARCH AND DEVELOPMENT EXPENDITURE (£m)



3

DEVELOP A COMPETITIVE PORTFOLIO OF PRODUCTS AND SERVICES

We have 40 major engineering programmes and we are involved in many of the future projects in the markets we serve. These key projects will define the power systems market for many years.

In 2010, we continued to bring new advanced products to market, including our new wave-piercing design of offshore support vessel. This vessel improves efficiency of operation and safety at sea for the crew.

UNDERPINNED BY CORE CHARACTERISTICS

Closeness to our customers
We recognise that our customers determine our strategy and organisation.

Domain knowledge
A deep understanding of our customers and the way in which our products and services are used.

4

GROW MARKET SHARE AND OUR INSTALLED PRODUCT BASE

Across our Group, the installed base of products in service is expected to generate attractive returns over many decades.

The Trent 700 is the market leading engine on the Airbus A330. The engine secured US$5 billion of business in the second half of 2010.

5

ADD VALUE FOR CUSTOMERS THROUGH THE PROVISION OF PRODUCT-RELATED SERVICES

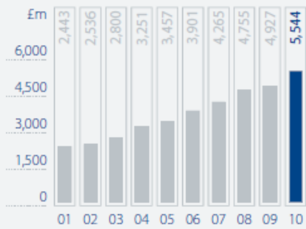
We seek to add value for our customers with aftermarket services that will maximise the performance and reliability of our products.

The increasing contribution from services
We have grown our service revenues ten per cent compound over the past ten years. Services account for over 50 per cent of total underlying revenue.

Underlying services revenue 2010

£5,544m

UNDERLYING SERVICES REVENUE (£m)



DELIVERING A 20-YEAR TRACK RECORD OF CONTINUED GROWTH

Organic growth
Our broad product range and expanding service provision have delivered growth globally.

Partnerships
We increasingly develop products with risk and revenue sharing partners and through strategic long-term relationships.

Acquisition
Major acquisitions such as Allison, Vickers and ODIM have enabled growth in key sectors.

Our growth during the past 20 years has been achieved largely organically but also through partnerships and acquisitions.

Integrated systems
Integrating our products into systems that deliver increased value for our customers.

Technological superiority
Gaining competitive advantage through continual investment in technology.

Operational excellence
Working constantly to meet and exceed customer expectations.

Organisational capability
Attracting and retaining the best people globally.

Brand
Recognised globally, our brand embodies qualities that create a common focus for all our people worldwide.

Appendix 2: Rolls-Royce Energy Product Portfolio

Data from www.rolls-royce.com/energy

Gas Turbine Engines:

Avon 200
As one of the world's most experienced aero derivatives, the industrial Avon gas generator that powers the Avon 2648 and Avon 2656 packages has consistently proven itself in applications both onshore and offshore.

Since introduction, the Avon has seen its power rating increase by 44 per cent and efficiency has increased by 14 per cent. The industrial Avon was introduced into service in 1964 and has developed a reputation for rugged reliability in the oil and gas industries, especially in North America where many units operate on trunk gas lines in Canada and the US, including on the oil pipeline in Alaska.

Indeed such is the durability of the Avon, that it recently established a 60 million-hour world record in its class of 10 to 20MW aero-derivative gas generators. Over 1,200 industrial Avons have been sold and the engine is the industry benchmark for reliability and availability.

Other applications include offshore pumping and compression, stand-by duties at nuclear power stations and combined cycle power generation.



RB211

The industrial RB211 is derived from the aerospace RB211, which is the chosen power plant for several large airliners.

Thanks to extensive development, the RB211 is the most reliable and easily maintained industrial gas turbine available today.

Auxiliary equipment such as intake air filtration, acoustics and lubrication all form part of the Rolls-Royce scope of supply for oil and gas and power generation applications.

The RB211 gas turbine package matches the technologically advanced Rolls-Royce gas generator with the efficiency of the RT62 or RT61 power turbine. The aero derivative industrial design has demonstrated outstanding reliability, with more than 650 RB211 gas turbines sold, accumulating a total of over 24 million operating hours of experience.

These gas turbine systems have been refined through experience, including remote and offshore applications where availability and reliability are of crucial importance. With superior performance retention and relative ease of overhaul, RB211 systems provide an ideal solution for today's applications.



Trent 60
The Rolls-Royce Trent 60 is the most advanced aero derivative gas turbine available today. Delivering up to 64MW of electric power in simple cycle service, at 42 per cent efficiency, the Trent 60 has established a new benchmark for fuel economy and cost savings. It also offers operator's fast delivery and installation times and beneficial performance.

Mechanical Drive
The Trent 60 is also available for onshore or offshore mechanical drive applications. The Trent 60 is ideally suited to meet the higher power, variable speed demands required by applications like natural gas liquefaction, gas transportation and gas injection for oil recovery. The design flexibility of the Trent 60 allows the same engine that serves the power generation market to meet the needs of mechanical drive service with no design changes.

Gas Engines:

Bergen B-gas & K-gas
Rolls-Royce Engines-Bergen provides a range of spark ignition (SI) gas engines based on its KV engine platform in the power range between 2,200-3,600 kWel. These engines are well established in the market and are highly competitive in terms of efficiency and emissions. The latest version, the KV-G4, producing between 2400 and 3640kW in 12, 16 and 18 cylinder versions, has changed the modern gas engine business by achieving higher efficiency compared with earlier spark-ignited gas engines, while also bringing down Nox emissions to new reduced levels.

Technical development has created one of the most cost-efficient engines available, with an output of 200kW of electrical power per cylinder at an efficiency of more than 46 per cent. These developments exploit advances in control and monitoring technology, both electronically and in terms of hardware.

The KV-G4 is ideally suited to today's CHP market and is backed by the world's finest pedigree of power – the experience of Rolls-Royce.

Bergen Engines

Compressors
Barrel centrifugal compressors
Product details
Available in four standard frame sizes, our multi-stage barrel compressors provide the oil and gas industry with natural gas gathering, re-injection, lift, depletion, storage/withdrawal and re-pressurisation solutions.

Barrel compressors are the preferred choice for high pressure ratios and the lower flow rates experienced in these applications.

Rolls-Royce uses advanced techniques to analyse each compression project to select the most flexible and efficient frame and rotor combination. For optimum performance predictability and production economy, each barrel frame size is based on families of standard impellers. The stationary flow path components are tailored to each application.

Pipeline centrifugal compressors
Product details
Six different models of pipeline compressors are offered with a choice of axial or conventional opposed inlets. Aerospace assembly techniques provide ease of maintenance with full removal causing no disturbance to the main piping.

Pipeline compressors are the preferred choice for the large flow rates required by natural gas transmission applications.

Our pipeline compressor aerodynamic performance has been refined to the point where conventional side inlet compressors offer up to 89 per cent polytropic efficiency and the axial inlet RFA36 achieves up to 91 per cent. Each compressor receives custom aerodynamic engineering of the entire gas path.

With flange sizes ranging from 508mm (20 inches) to 1067mm (42 inches) our conventional side inlet pipeline compressors can accommodate up to five stages of compression although only one or two stages are usually required for pipeline transmission duty.

The axial inlet RFA36 is the most efficient pipeline compressor in service featuring horizontal discharge and a single-stage, spherically shaped cast casing. Compact and rugged, the RFA36 weighs only two-thirds as much as a conventional pipeline compressor.

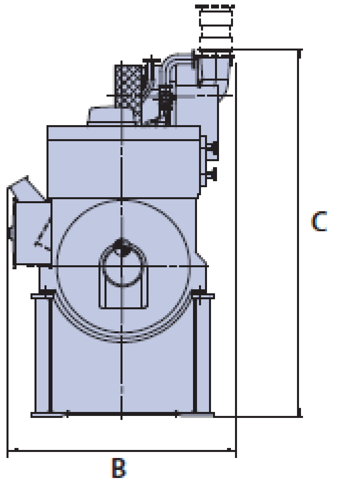
Diesel engines

The Bergen B32:40 diesel engine is a result of continually improved technology, material and our customer' valuable experience. It is the tomorrows' solution today. The Bergen B32:40 is a powerful and reliable diesel engine based on traditional diesel strengths, which always has been evident in our well proven BR- and BV models. All major components are designed for long, trouble-free operation and good accessibility provides easy overhaul.

The Bergen C25:33 family, launched in 2002, exploits more than 60 years experience in the 250mm bore segment, and is based on modular design to deliver a truly modern engine that is compliant with World Bank emissions regulations.

It has a track record of very low life cycle costs and is designed for long service intervals. The engine is also simple to maintain. The liner, piston, (Inc upper con rod) and cylinder head can be replaced as a single unit, without disturbing the big end bearing, saving users a lot of time and money.

The C25:33 is available in 6, 8 and 9 cylinder versions with power from 1,245 to 1,870kWe @ 720rpm and 1,300 to 1,945 kWe @ 750rpm. The same cylinder versions are also available from 1,505 to 2,260kWe @ 900rpm and from 1,560 to 2,340kWe at 1000rpm.



Fuel Cells

The Rolls-Royce fuel cell system is lower cost; more efficient; more easily distributed; more durable and maintainable than its nearest rival.

Rolls-Royce has experience in the system integration of several different types of fuel cells and believes the Solid-Oxide Fuel Cell is the best for stationary power generation applications while retaining the capability of being developed subsequently for various transportation, military and marine applications.

Appendix 3: Inventory Costing Formulas

These formulas have been calculated by Stock & Lambert (2001) :

Cost of capital

Cost of Capital = Cycle Inventory x *I* +Safety inventory x *I* +Inventory in transit x *I*

To calculate the holding costs of cycle inventory is:

Holding costs for cycle inventory = $\frac{Q}{2} \times C$

where, Q = order quantity, C = cost per unit

To calculate the holding costs of holding inventory whilst in transit is:

Inventory in transit = D x T

where, D = the average flow time per unit (the order quantity times number of orders), T = Transit time.

Economic Order Quantity

The EOQ model is calculated by evaluating the impact of holding costs and ordering costs that determine the total cost. This information was evaluated by Slack et al (2001)

Holding costs = holding cost/unit x average inventory

$$= C_h \times \frac{Q}{2}$$

Ordering costs = ordering cost x number of orders per period

$$= C_o \times \frac{D}{Q}$$

Total cost C_t

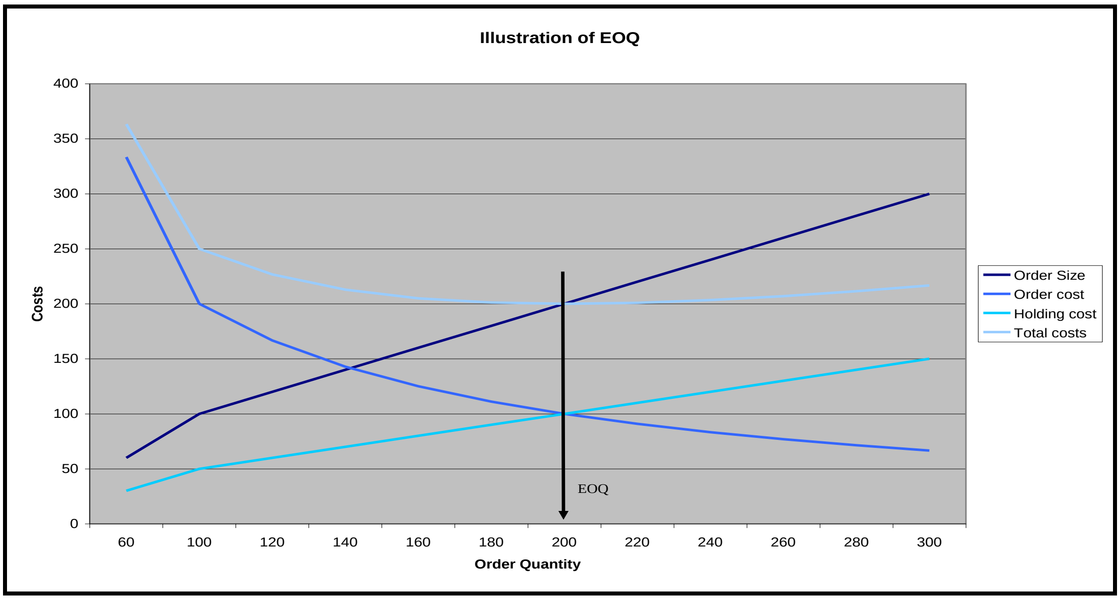
$$= \frac{C_h Q}{2} + \frac{C_o D}{Q}$$

Using this information, organisations can evaluate the impact of having different order quantities, see table below.

Demand (D) = 1000 units per annum
Holding costs C_h = £1 per item per annum
Order costs C_o = £20 per order

Order quantity (Q)	Holding costs ($0.5Q \times C_h$)	Order costs ($(D/Q) \times C_o$)	Total costs
50	25	20 x 20 = 400	425
100	50	10 x 20 = 200	250
150	75	6.7 x 20 = 134	209
200	100	5 x 20 = 100	200
250	125	4 x 20 = 80	205
300	150	3.3 x 20 = 66	216
350	175	2.9 x 20 = 58	233
400	200	2.5 x 20 = 50	250

Based on these results the lowest total costs for satisfying annual demand of 1000 units would be to place an order for 200 units, which are illustrated in the chart below.



Appendix 4: ERP definitions

ERP Description	Reference
An ERP system can be thought of as a company-wide Information System that tightly integrates all aspects of a business. It promises one database, one application, and a unified interface across the entire enterprise.	Bingi et al., 1999, p. 8
ERP systems are highly integrated enterprise-wide standard Information Systems (software packages) that automate core corporate activities (business processes) such as finance, human resources, manufacturing, and supply and distribution.	Holland et al., 1999a, p. 289 ; Holland et al., 1999b, p. 273
ERP is an integrated package of software applications designed to automate and integrate a company's business processes throughout its entire supply chain and to provide immediate access to business information. ERP systems can be thought of as wide-ranging, general-purpose management information systems (MIS) for business.	Maher, 1999, p. 36
ERP systems, a form of Enterprise-Wide Information System (EWIS), represent sets of business applications that allow for an organization-wide management of operations. ERP systems are seen as optimization and integration tools of business processes across the supply chain (within and beyond organizational boundaries) implemented through modern information management systems.	Al-Mashari, 2000, p. 3
ERP is known as a large-scale, cross-functionally integrated, packaged system.	Brown et al., 2000, p. 1029
ERP systems are software packages that integrate information across the entire organization. This integration removes inconsistencies and enables the organization to attain consolidated reports.	Shakir, 2000, p. 1033
ERP is an integrated comprehensive Enterprise-Wide Information System.	Milford & Stewart, 2000, p. 951
ERP is a comprehensive Information Technology package built on the promise that all critical information should be totally integrated in a single information database.	Wood & Caldas, 2001, p. 387
ERP links all areas of a company with external suppliers and customers into a tightly integrated system with shared data and visibility. ERP systems are designed to solve the problem of the fragmentation of information over many legacy systems in large business organizations.	Chen, 2001, p. 374; Chen, 2001, p. 379
ERP systems are comprehensive, fully integrated software packages that provide automated support for most of the standard business processes within organizations.	Shanks et al., 2000, p. 537

An ERP system is a packaged business software system that enables a company to manage the efficient and effective use of resources (materials, human resources, finance, etc.) by providing a total, integrated solution for the organization's information-processing needs. It supports a process-oriented view of the business as well as business processes standardized across the enterprise.	Nah et al., 2001, p. 285
ERP systems allow a company to share common data and practices across the enterprise and produce and access information in a real-time environment. These systems are designed to solve the fragmentation of information in large business organizations and to integrate information flow within a company.	Themistocleous et al., 2001, p. 195
ERP plays a critical role in improving or reengineering outdated infrastructures, gaining tighter control over internal operations, and driving down costs.	Turban et al., 2001, p. 303
ERP consists of massive computer applications that allow a business to manage all of its operations (finance, requirements planning, human resources, and order fulfilment) on the basis of a single, integrated set of corporate data.	James & Wolf, 2000
ERP systems are large and complex integrated software packages that support standard business activities.	Oliver & Romm, 2000, p. 1039

From: Adam & Sammon (2004)