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MANUFACTURING PROCESS OPTIMIZATION WITHIN A FURNITURE SME

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DECLARATION OF AUTHOR'S RIGHT

ABSTRACT

This dissertation describes the findings of research completed in a timber furniture manufacturer SME when carrying out an integrated improvement programme. This work aimed to enhance the manufacturing processes of the company and identify lessons of general applicability to similar industries.

A changing market scenario has resulted in an increase in price and product quality competition within the furniture industry. This has led to a more complex and diversified customer demand characterised by short production lead-times and small batches. Within this environment the organization identified an urgent need to investigate and enhance its manufacturing processes in terms of performance and flexibility in order to increase competitiveness. In parallel it also needed to establish suitable manufacturing capability and performance measurement systems.

As a result the implementation of a structured programme of continuous improvement of the manufacturing processes has been carried out by the author to allow the company to establish and maintain a competitive edge within the furniture sector. A thorough analysis of the manufacturing processes was conducted resulting in the identification and implementation of beneficial modifications that allowed the business model to be successful within the new market requirements.

General findings applicable within the furniture manufacturing sector have been identified from the results obtained at project completion, such as accurate identification of machinery capabilities, increase of the overall manufacturing efficiency in terms of reduced lead time, work-in-progress, and rework/wastage rates as well as improvements in product quality which led to additional sales of existing and new lines of products.

The integrated improvement programme provided a unique case study that allowed novel insights to be gained and filled a gap in existing academic and industrial knowledge. This gap was identified as a lack of documented manufacturing improvement programmes conducted in traditional labour-intensive companies operating within the woodworking industry.

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GLOSSARY OF TERMS

AMT	Advanced Manufacturing Technology
BSI	British Standards Institution
CI	Continuous Improvement
CSF	Critical Success Factor
DFM	Design For Manufacture
DOE	Design Of Experiment
ERP	Enterprise Resource Planning
FMC	Flexible Manufacturing Competence
FMEA	Failure Mode and Effect Analysis
HOQ	House Of Quality
ISO	International Organization for Standardization
JIT	Just-In-Time
KPI	Key Performance Indicator
KTP	Knowledge Transfer Partnerships
MS	Method Study
MRP	Material Requirements Planning
MRPII	Manufacturing Resource Planning
OEE	Overall Equipment Effectiveness
OIP	Operations Improvement Practices
OTE	Overall Throughput Effectiveness
PCP	Process Control Procedures
PPO	Product and Process Optimization
QFD	Quality Function Deployment
QM	Quality management
QMS	Quality Management System
QRM	Quick Response Manufacturing
SME	Small to Medium-sized Enterprise
SPC	Statistical Process Control
SQC	Statistical Quality Control
TBC	Time-Based Competition
TPM	Total Productive Maintenance
TQC	Total Quality Control
TQM	Total Quality Management
VIM	Visual Interactive Modelling
VSM	Visual Stream Mapping
WMS	Work Method Study
WIP	Work-In-Progress

1 Introduction: Background and Context

This research project is based on a Knowledge Transfer Partnership (KTP) between the JRG Group Ltd and the University of Strathclyde.

The aim of the KTP programme was to optimize the manufacturing processes within the JRG Group and bring new knowledge on the woodworking and furniture manufacturing SME industry to the academic world.

This chapter firstly describe the background of the researcher who carried out the project. Then it introduces the JRG Group Ltd, the company at the focus of this research programme, and explains its history, purpose and business goals.

The chapter then shows the research project's context and how the KTP programme helped the company to understand its manufacturing capabilities and develop its manufacturing strategy. Finally, an overview of the research study based on the KTP project carried out at the company and at the base of this dissertation is presented.

It is also important to notice that, although the project research work was focused on a single case study representative of a typical furniture manufacturing SME within the UK, this academic study is in depth and the results have more general applicability within the furniture manufacturing sector.

1.1 Researcher's Background

On September 1996 the researcher registered at the faculty of Engineering at the University of Parma (Italy), where he graduated in April 2001 with a degree in Mechanical Engineering, Logistics and Manufacturing Management. In 1999-2000 he carried out a six-month internship working on a research project which was one year later submitted as his final thesis for the Degree in Mechanical Engineering with title: "The Thermodynamic Method in the Valuation of the Efficiency of a Hydraulic Pump".

From May 2001 to August 2005 the researcher was employed in Parma (Italy) in a company involved in the design, installation and maintenance of electrical plants, control boards and data networks for the industrial market. His main responsibilities were managing and maintaining the Quality Management System ISO 9001:2000, managing the stock, purchasing materials, managing the IT local area networks and dealing with suppliers and customers.

Between July 2003 and September 2003, while he was employed at the company, he also gained the "Chartered Industrial Engineer" status at the Mechanical Engineering Faculty of the University of Parma (Italy).

In September 2003, while the researcher was still working, he also registered again at the faculty of Mechanical Engineering of the University of Parma (Italy) to carry out a complementary degree in Mechanical Engineering. Between September 2005 and July 2006, after leaving his job at the company, he registered in Glasgow (Scotland, United Kingdom) as an exchange student on a nine-month research project with the Design, Manufacture and Engineering Management Department (University of Strathclyde, Glasgow – Scotland, UK) which involved several Scottish manufacturing and service companies.

In September 2006 the research work completed in Glasgow was submitted as final thesis for the complementary degree in Mechanical Engineering at the University of Parma (Italy) with the title "A Model to Measure the Level of Success of the Implementation of New Technologies in Manufacturing and Service Industries".

During his research study carried out in Scotland for the complementary degree in Mechanical Engineering, the researcher had the opportunity to deal with some associates working on Knowledge Transfer Partnership (KTP) programmes in companies in the Glasgow area and he learned about the opportunities for graduates to be part of these projects. Very soon they attracted the researcher's interests, and after he graduated in Italy in September 2006, he immediately applied for a KTP project between a Scottish furniture manufacturing company (the JRG Group Ltd, Irvine - Scotland) and the University of Strathclyde, this application was successful. The researcher started the programme in February 2007. He was employed on a full-time basis within the role of Process Quality Engineer as a KTP associate working on a two-year collaboration project between the company and the University of Strathclyde.

In June 2008, while still carrying on the KTP programme, the researcher was promoted from the position of Process Quality Engineer to the role of Production Manager. Along with the tasks of the KTP project, he was assigned more responsibilities including monitoring the production processes in compliance with the ISO9001:2000 Quality System, reporting on manufacturing scheduling issues, carrying out daily meetings with the departments' team leaders, supervising the production teams, implementing new manufacturing processes in the shop floor when required, identifying maintenance requirements of the production equipments and machinery, assessing competences and identifying training needs of the shop floor operators, and liaising with the Research & Development personnel regarding design-related issues.

During the two-year research project carried out at the company the researcher had the opportunity to undertake many training courses in order to enhance his knowledge and expertise in several business areas. In particular, in May 2007 he attended with "Granger's Consultancy Services" an "ISO 9001:2000 Internal Auditing" 5-day training course on principles and theory of internal auditing an ISO9001 Quality System and reporting upon the findings. In June 2007 he undertook with "CRAC, The Career Development Organization" two 5-day courses: "Managing for Results", regarding managing personal development, information and managing and planning projects and “People Skills”, regarding Managing quality, relationships and change and communicating effectively. In October 2008 the researcher attended in Eindhoven (Holland) with “LeanTeam” a training course on “Quick Response Manufacturing (QRM)” concerning the Quick Response Manufacturing methodology principles and strategy, including its four core concepts: the power of time, organizational structure, system dynamics, and enterprise wide application. Finally, in January 2009 he undertook with “Ashorne Hill Management College” a 5-day course on “Business Leadership and Career Development” about leadership and entrepreneurial skills and developing and realizing business goals.

The two-year KTP project the researcher carried out as Process Quality Engineer and Production Manager with the JRG Group (Irvine, Scotland – UK) and the University of Strathclyde (Glasgow, Scotland – UK) between February 2007 and February 2009 aimed to enhance the competitiveness of the company by analysing and improving the manufacturing processes and customer satisfaction, introducing control techniques and recording procedures and methods. The programme gave him the opportunity to be involved in the manufacturing industry research field by combining a work experience and applying specific techniques he studied at the university as a student. Being employed on a fulltime basis within the company and carrying out the manufacturing improvement project as a KTP associate provided him with a unique chance to study more in depth the opportunities and the issues related to the measurement and the achievement of manufacturing processes optimization within the furniture SMEs industry. The final outcomes of the researcher’s project have helped the company to achieve the expected improvements and bring to the academic world a new case study and new knowledge about the woodworking sector.

The researcher’s past academic and work experiences provided him with a significant level of technical and engineering management expertise, good knowledge of manufacturing engineering and manufacturing process planning and control tools.

In particular, the researcher developed social skills such as good team spirit and good ability to adapt to multicultural environments as well as effective communication and strong interpersonal skills. Through his past work experience he also had the opportunity to enhance his organizational skills by improving his ability to manage efficiently the tasks and achieve the goals requested, to work under pressure and deliver by the deadlines through a logical and practical approach to the daily work duties. The researcher also developed a high level of attention to details, good leadership skills, and a good sense of management of people gained through his work experience by supervising the employees during their daily work activities and by managing 3 six-month student projects carried out during the KTP programme with the University of Strathclyde and the JRG Group Ltd on “Quality Function Deployment (QFD)”, “Manufacturing Process Software Simulation” and “Cost of Quality”.

As far as technical skills are concerned, the researcher’s past training and work experience allowed him to gain an excellent knowledge of the ISO 9001:2000 Quality Management

System standard requirements and internal auditing techniques as well as excellent command of Microsoft Office™, Computer Aided Design (AutoCAD™) and manufacturing processes simulation (Simul8™) software. Furthermore, his academic background consented him to accomplish good command of very specific production process control and optimization tools, such as Failure Mode and Effect Analysis (FMEA), Quality Function Deployment (QFD), Process Control Procedure (PCP), Statistical Process Control (SPC), Material Requirement Planning (MRP), Manufacturing Resource Planning (MRPII), 6-Sigma techniques etc..., some of which have then been utilized to a partial or great extent during the manufacturing improvement programme carried out at the company.
The expertise achieved through the past work and academic experience by the researcher, along with effective project management, communication skills and ability to work independently or as part of a team developed in the past years, proved to be very beneficial to communicate effectively at all levels and to address properly the objectives of the project.

1.2 The Host Company: the "JRG Group Ltd"

The JRG Group is an independent manufacturing company based in Irvine (Ayrshire) in the west of Scotland. The company, which started in the mid 70's as a family business and has now expanded to employ around 70 people, operates in the extremely competitive wood-based furniture manufacturing sector. The core of the company's manufacturing technology is based around Medium Density Fibre (MDF) board processing for the production of bedroom and kitchen furniture, fireplaces, fireplace surrounds, inserts, mantels, hearths in a wide variety of colours and finishes.
The company's factory is located in Irvine (Ayrshire) and it is one of the largest employers in the area. The factory is based on two levels, with the main production area on the lower floor and the administration offices area on the upper floor. The overall factory floor consists of 80,000 sq. ft. sitting within 12 acres with room to expand. The company's facilities include 140 parking spaces, hard-standing room for over 100 containers, 12 shipping bays and a fleet of delivery vehicles and trucks. The company provides a home delivery service for the UK customers and exports to eight countries.
For over 30 years, the JRG Group have been at the forefront of design, innovation and manufacture which allowed the company to be the first into the market with innovative and practical products with an international reputation for style and quality. All the product ranges are created and manufactured in Scotland and are produced using eco-friendly methods and sustainable materials, bearing the stamp of the company's quality and reliability. The reputation of the company has been built over the years on the experience as a manufacturer that combines high quality and craftsmanship with value for money.

The JRG Group is also one of the leading British manufacturers of electric suites and fire surrounds in the United Kingdom and the largest in Scotland. The other product ranges have grown over the past years to include furniture, kitchen and bathroom ranges, both free-standing and fitted. The company, in fact, went recently through a period of substantial change trying to gain entry into new markets such as bedroom and kitchen furniture rather than keep focusing its main production on fire surrounds as it used to be in the past years.

Moreover, the JRG Group actively seeks to work with designers and developers to introduce top quality and innovation to products and services that bring real added value to finished developments. In particular, the company is active in the new build and refurbishment construction markets, such as house building, hotel furniture, healthcare furniture and freestanding/fitted furniture. The company is an approved and specified supplier by local authorities, councils, housing associations, house builders, contractors and electrical and furniture retailers.

1.2.1 JRG Group's Business Model

The JRG Group's business model can be summarised as follows:

"The design, manufacture and sale of a wide range of bespoke timber products such as bedroom and kitchen furniture, fireplaces, fireplace surrounds, inserts, mantels, hearths in a wide variety of colours and finishes based on Medium Density Fibre (MDF) board processing" (source: ISO9001:2000 Quality Management System certificate of "JRG Group").

The JRG Group business model makes the company unique within the Scottish timber furniture industry in being able to provide complete ranges of furniture products for the housing and caravan markets including:

- fire surrounds, wall fires, bedroom furniture, kitchen furniture, bathroom cabinets, sliding doors, vinyl wrap doors, interior doors, and other MDF-associated components.

The company is now regarded in Scotland as one of the few complete furniture range manufacturers competing in both the refurbishment and the new build market.
In the recent years, the JRG Group was able to capitalise on the growth in this sector which was fuelled by the rapid growth in house prices. The high product quality standard and the growth in demand in the housing market allowed the company to increase its prices which in turn increased its product volumes and, consequently, its turnover. In order to cope with the increased manufacturing volumes and to increase the production output, in 2005 the

company moved to a larger facility, which, as mentioned above, now consists of an overall factory floor of about 80,000 sq. ft. and extended its machine shop production capabilities by buying new state of the art machinery and equipments such as a second beam saw, a second automated CNC machine and a vacuum membrane press for high volumes and skilled personnel.

1.2.2 Product Portfolio and Position in the Market

During the very first years the JRG Group started operating on the market, the first products designed and manufactured were represented by timber fireplaces and fire surrounds in an assortment of colours and wood finishes.

Before the start of the KTP research programme at the company, the main competitors within the fire surround sector held around 55% of the market share. The total market was worth in the region of £110M and the JRG Group occupied approximately 4.3% of this market which equated to about £4.8M. The company was aiming to increase their market share to 8.6% and as the overall market was forecast to grow to around £140M, this equated to a projected turnover by the third year after the project completion of £12M *(Source: MSI (Marketing Strategies for Industry) Data Brief – Domestic Fires and Fireplaces, UK).*

The market for caravan fireplaces was estimated to be worth in the region of £7.5M and the JRG Group occupied approximately 10% of this market (£750K). It was anticipated that gaining ISO9001:2000 certification would have enabled the company to capture an additional £300K of this market. An average of 19,000 new private sector homes per annum was built in Scotland between 2000 and 2004. It was estimated that the market for new fire surrounds within this sector was worth a potential £2.28M and the company aimed to target 35% of this market worth £798K (*Source: Scottish Executive Statistical Bulletin: HSG/2005/5: Housing Series: Housing trends in Scotland).*

The product range in the recent years was extended to include wood finished furniture for both lounge and bedrooms. Recently the company increased the product variety even further with the addition of kitchen furniture and wooden internal doors. All theses products have been added within the current capabilities in terms of machinery and personnel at the production facility. In the recent years, as the market furniture styling changed according to more and more demanding customer requests, the designs offered by the JRG Group became more contemporary. As far as fireplaces are concerned, the company offers a wide range of suites, surrounds and wall mounted products, a total of 32 variations throughout the range, each in various wood finishes. As far as lounge, bedroom and kitchen furniture is concerned, the range is smaller, however the variation of wood finish is greater, with around 10 various styles available.

The company is also an approved distributor of Dimplex, a world leader in opti-flame effect fires which are used with fire surrounds in different colours and models to create fire places.

2 Situation at the Company before the Start of the Project

2.1 New Market Requirements

After the company moved to the new factory, the market scenario started to change and to include more diversified and complex customer demands as a consequence of an increase in price and product quality competition in the furniture industry. In particular, the sector new requirements started to move from short lead-time high volumes of standard product ranges to small batches of more customised products.

The company therefore realised the need to analyse, improve and enhance the flexibility of the manufacturing processes in order to, ultimately, increase its competitiveness.

Moreover, the new automated machinery, the increased training requirements for the production operators and the need of highly customised and diversified products all contributed to increase the flexibility requirements of the manufacturing processes and to raise the operating costs of the established business model.

Although the company's larger facility potentially allowed the JRG Group to handle high volumes of small product batches as requested by the market, the manufacturing processes and the capabilities of the machinery needed to be reanalysed and restructured in each production department in order to cope with the new industry scenario - as explained above, now characterised by small volumes of highly bespoken products - by achieving reasonable manufacturing lead-times.

Furthermore, in the recent years, the company was failing to adequately capture customer requirements leading to high levels of redesign and rework. They were not able to specify their manufacturing capability (e.g. tolerances) and their manufacturing procedures were inadequately specified leading to variations between operators. Also, the production processes were not optimised and the performance was not adequately measured. Overall, the manufacturing operations were; continuing to rely too much on 'craft' skills, delivering inconsistent quality, creating a high level of rework. Additionally both efficiency and wastage could be improved. As mentioned, the company had recently moved into a large modern factory and employed a new management team driving their strategic development. By controlling their costs and delivering high quality consistently, they could have secured existing business and enabled growth in current and new markets. Moreover, it appeared clear to the JRG Group's management that implementing an ISO9001:2000 Quality Management System and gaining accreditation could have facilitated new business opportunities by entering into a number of new markets.

2.2 How to Achieve and Maintain a Competitive Edge in the Marketplace

As previously mentioned, the type of industry the JRG Group was operating in was becoming very competitive, and, as a consequence, price represented the main order winner for many of the products the company manufactures. Until a few years ago, most of the sales that the JRG Group obtained were from house builders and wholesalers, who used to order large quantities to fit out new build houses. Only a small amount of the sales were generated through private sales. The recent global recession of the economy forced the JRG Group to analyse the actual market and to look to reduce costs where possible, in order to compete with larger companies who can produce the same goods at much lower prices. Moreover, in the recent years a more and more specific customer demand along with a higher and higher level of competition in product cost and quality defined a new market trend characterised by smaller production batches and shorter manufacturing lead-time.

To maintain a competitive edge, the company recently expanded its ranges of timber furniture and fire surrounds so that they can offer their clients a greater choice of products. This product range expansion occurred within the current limits of the production facility, allowing greater variety, at little cost. The company has recently moved to expand its product variety even further by introducing the production of a range of timber internal doors, which required re-design and re-development of the production lines and some new machinery. The new process also required to be thoroughly analysed through a work method study with the aim of fully optimising and streamlining the production processes in terms of time spent on the job batches, so that profit per unit could have been maximised. One of the main competitors for orders of the newly introduced internal door range was able to produce the output in much shorter lead times and, therefore, lower costs due to the lower incidence of the labour. This was mainly due to machinery, which was much more advanced and had a higher capacity level than those being used at the JRG Group. The competitor was also using specific equipments exclusively for the internal door manufacturing process, whereas at the JRG Group most of the machines were being used for several of the various products they offered.

Obviously, the easier solution to these problems would have been to create a new manufacturing facility that could have responded to the changes and needs of the company. Another ideal option would have been to secure outside investments in the company which would have both secured orders and also provided capital for new machinery and expansion of the production line to increase the capacity. However, unfortunately, the economic climate made these solutions highly impracticable. Due to the economic recession and instability in the market, the JRG Group, in order to compete for orders in the actual marketplace,, had to achieve a competitive edge which required a minimal capital investment.

2.3 Manufacturing Issues

The manufacturing processes carried out in the shop floor to create the various products were all quite similar to each other. Raw materials were cut and treated before being assembled to produce the final products. The overall manufacturing process was very labour intensive and this represented one of the highest costs in production. Because the variety of products offered was wide, the machines took long times to carry out the changeover operations between different product batches and this was reducing the flexibility which the company needed in order to maintain a competitive edge on the market. Many products were processed through similar operations but the layout of the factory was not optimised to cope with this situation and it could be improved to reduce material flow through the various machines. Another issue was represented by the difficulty in the movement of each product due to the various sizes of component parts which needed to be cut and treated. These problems highlighted the urgent need of streamlining the manufacturing material flow by modifying the machinery and operations layout in the factory floor for some of the production processes.

The factory was working near capacity limits in terms of both production levels and also product range. When the company introduced further ranges to the already large product portfolio in order to cope with the customer demand, a new manufacturing scenario characterized by an increased strain on the available resources arose. The site where the company was operating from had the capability to expand depending on the success of the new product introductions and also this aspect was investigated further during the programme.

The main issues which affected the company and needed to be addressed in order to optimise and streamline the production processes and to continue generating are summarised as follows:

- Poor layout causing complex material flow, especially after the introduction of new product manufacturing processes (e.g. internal doors, new ranges of furniture);
- Lack of quantitative and, to a certain extent, qualitative performance measurement data;
- Incorrect work methods used sometimes by the operators during the daily activities;
- Some of the machines sometimes working over capacity due to high volumes of similar products processed at the same time;
- Some of the machines sometimes working under capacity due to lack of trained staff;

- Process capability not properly analysed;
- Production scheduling and planning based only on machinery capacity without taking into consideration the mutual interactions of the production processes;
- Incomplete manufacturing controlling tools;
- Lack of proper communication flow and interactions between manufacturing departments;
- Most of the workforce only trained to process specific types of products;
- High levels of rejects, reworks and waste which increased the incidence of labour on final costs for the customers;
- Manufacturing and design processes not fully oriented to focus on customer requirements in terms of final product due to lack of understanding of client needs;
- Some quality issues due to lack of full technical knowledge and understanding of some new manufacturing processes;
- Lack of quality controls (final inspections, intermediate check-points, etc…).

These problems had serious “knock-on” effects within the manufacturing processes causing high volumes of work-in-progress and long production lead times resulting in customer dissatisfaction due to late product delivery dates.
The workers’ morale was also low as they viewed the company failing to satisfy the clients, no matter what effort they put in to improve the work processes.

As the company needed to improve its production processes to match rival bids, they also needed to train multi-disciplined staff. Before the start of the improvement programme, the workers were only skilled to use specific machines. This resulted in machines being under-utilised since there was lack of trained operators to run them, causing bottle necks in the production lines. Improving the manufacturing processes also in terms of operators cross-training would have enabled the production personnel to be moved around the facility and operate machines where and when necessary, in order to meet production deadlines.

2.4 Need of Improvements

As said earlier, due to the global economic climate which affected the company as well, the JRG Group, in order to pursue and maintain a successful position in the marketplace, had to achieve a competitive edge which required a minimal financial investment.
At that point it appeared clear that a structured and thorough analysis of the manufacturing processes required to be carried out and beneficial modifications to those processes needed to be identified and applied in order for the business model to be still successful in the new market requirements - where the dominant features of the social housing sector such as

sameness, volume and price competitiveness where not relevant any longer. The implementation of an integrated continuous process improvement programme was strictly necessary in order for the company to establish and maintain a competitive edge within the timber fireplace and furniture sectors.

In particular, before the issues affecting the production processes could have been resolved, the company had first to analyse the current capabilities of the facility in place so that they could have been adjusted accordingly and increased if needed. A work study and simulation analysis became strictly necessary to allow the company to identify areas where bottlenecks and high volumes of inventory were occurring. Once this was carried out, the company was then able to take appropriate actions in order to avoid such issues as well as implementing the new products (e.g. new furniture ranges, internal doors, etc…) into the production line. This became possible through a thorough analysis of the factory layout changes, the capacity increases and the other production process modifications which were required to meet the order times.

Therefore, within the proposed outcome, the re-design of the production line and the increase of the staff training levels have been analysed in order to properly accommodate new product lines within the actual manufacturing capacity and to decrease as far as reasonably practicable the job batches' manufacturing lead time and work-in-progress. As it was mentioned earlier, there was a generic process that most of the products at the JRG Group were following, with small deviations and additional processes required, depending on the type or style of the product being manufactured. This process has allowed a re-design of the shop floor layout in order to optimise the product flow, which has helped to reduce the inventory and shorten the production lead times, all these contributing to increase the flexibility of the manufacturing processes of the company. To this purpose, a variety of theories has been investigated and applied by using also software simulation in order to find the most suitable and practicable solutions for the company.

3 Knowledge Transfer Partnership Programme at “JRG Group”

3.1 Overview

A KTP programme is a research programme partially funded by the Department of Trade and Industry (DTI) and the Scottish Executive in which a graduate called “associate” spends a defined period of time - in this case two years - in the company working on a programme of strategic importance to the business. The programme ensures that the company adopts a structured approach when introducing new equipments, processes and work techniques through appropriate analytical and project management tools and techniques. In return, the research institute – in this case, the Design, Manufacture and Engineering Management (DMEM) of the University of Strathclyde - uses the company as a case study for the academic world for new methodologies or testing tools and techniques in new environments. As mentioned above, the new business priority led the JRG Group to partner with the Design, Manufacture and Engineering Management (DMEM) of the University of Strathclyde and to start in 2007 a 2-year Knowledge Transfer Partnership (KTP) project with the aim of improving and optimising the manufacturing processes and capabilities of the company in order to achieve high quality product through short production lead-times in a new market scenario constituted by small batches of highly bespoken product ranges.

This partnership was strategic to the JRG Group since it perfectly integrated and followed-up a first KTP project which was carried out in the past years at the company and focused on implementing an enhanced product design and development process, with the aim of reducing product development lead time and improving product quality. However, the recent move to larger premises and a projected increase in business over the following years have reaffirmed the company’s management beliefs that there was an immediate requirement for a second KTP project. JRG Group had ambitious growth plans and was looking to consolidate their established position in both the timber fireplace and furniture markets, in addition to increasing their market share as a supplier to the caravan industry. This was to be followed by the penetration of new markets such as the house building. This was only to be achieved through the implementation of an integrated continuous process improvement programme by taking a holistic view of the manufacturing process.

3.2 Aim and Objectives

The KTP programme carried out with the JRG Group and the University of Strathclyde sought to analyse and review current manufacturing processes and working practices by introducing shop floor measurements and mapping the “As-Is” process. From the review a “To-Be” process would be developed by modifying existing processes and practices, incorporating new working methodologies and introducing new manufacturing procedures.

The two-year collaborative KTP project was, in particular, centred on the task of investigating and improving the company’s manufacturing processes and customer satisfaction through an integrated programme which included the following specific activities:

- Implementing a Quality Management System ISO9001:2000 and gaining accreditation,
- Introducing manufacturing Key Performance Indicators (KPIs),
- Carrying out Work Method Study and implement improvements,
- Performing a Machinery Capability Study for each product line,
- Carrying out Value Stream Mapping and performing Manufacturing Process Software Simulation,
- Implementing an enhanced manufacturing planning tool in the shop floor,
- Developing a Quality Function Deployment study (QFD), and
- Performing Failure Mode and Effect Analysis (FMEA) and implements improvements.

The main aim of the project - i.e. enhancing the competitiveness of the company by analysing and improving the manufacturing processes, introducing control procedures for these processes, and clearly recording the procedures, processes and methods as described above - was only to be achieved through the implementation of this structured continuous process improvement programme.

The ultimate goal of the KTP project was to allow the JRG Group to gain entry into new markets. Fundamental to this approach was the need to develop continuously improving process control operations in order to achieve an advantage position to compete for future markets.

The project was fully supported by expertise from the Department of Design, Manufacture and Engineering Management (DMEM) at the University of Strathclyde. This support included an individual development plan, personal training and support from the academic and the company supervisors.

4 Research Methodology

The first chapters of this dissertation explained the background to and the origins of the research problem. As mentioned earlier, using the JRG Group as a case study the purpose of this research is to investigate the problems in achieving and measuring the manufacturing process optimisation obtained through the implementation of an integrated improvement programme at the host company.

Research methodology plays a fundamental role in any type of research if the aim is to demonstrate credibility. A lack of analysis and validation of the philosophical nature of the research might affect the quality of the findings of the research. How the researchers understand and interpret the reality of the world influence the research process and its outcomes. Hence, the philosophical assumptions help the researcher to choose the right research methods and techniques. What is in the world and how the researchers know it are broad questions to investigate in research philosophies discussions. As a result, researchers focus on different paradigms due to their choices to look at the social world from various prospectives.

The area of research methodology is wide and varied and includes a number of terms, definitions and philosophical arguments which need to answer questions like:

- What is research?
- Who is a researcher?
- Where do research problems originate
- How should the researcher go about solving the problem?
- Where should the researcher go for the information?
- How does the researcher know if the problem is solved?

The choice of the correct research methodology is essential because it “drives” the whole nature of the research programme. A methodological process includes a number of phases which a researcher follows to answer the research questions.
Martinez and Albores developed a model in 2003 which in their views describes the various stages in developing a methodology as it is shown in figure 4.1.

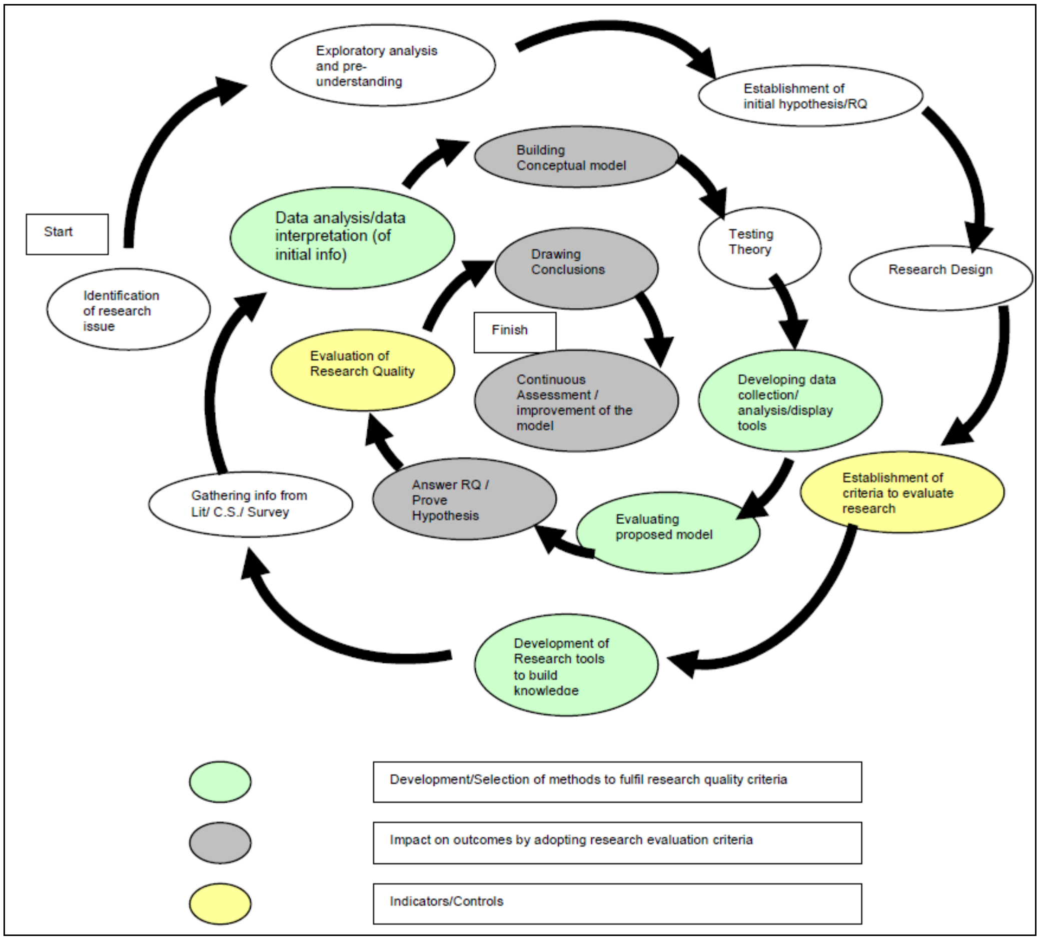

Figure 4.1 - Research methodology process (according to Martinez and Albores, 2003)

4.1 Research Approaches Available to the Researcher

As previously explained, it is fundamental for a research programme to follow a suitable methodological approach. The purpose of this chapter is to develop an understanding of the wide range of methodological choices available to the researcher, including an overview of their main features regarding data collection, principles of data analysis and theory building.

There are different research approaches which can be explained through four dimensions, i.e. ontology, epistemology, methodology and methods/ techniques. It is then possible to draw a map of ways of designing the research through selecting a paradigm, epistemology, methodology and related methods and techniques as shown in figure 4.2 (Beech, 2005). In any research design these fundamental choices are critical to ensure credibility of the academic study.

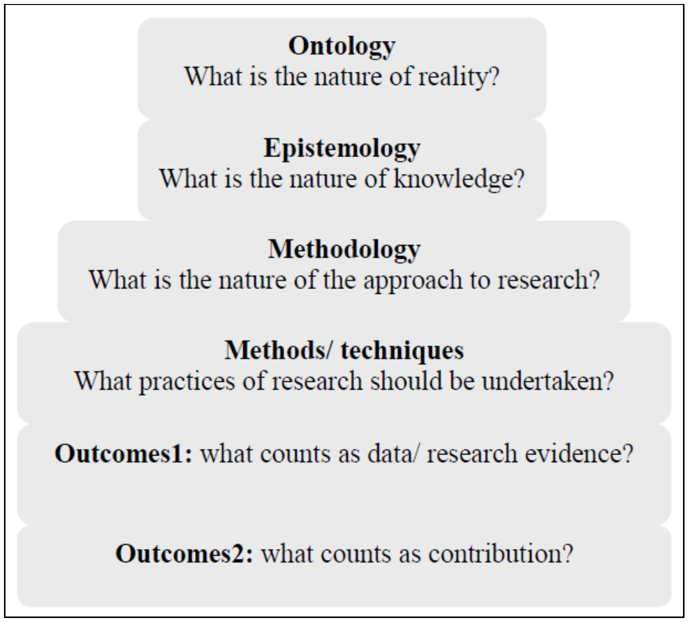

Figure 4.2 - Research methodology design building blocks (Beech, 2005)

The following paragraphs review the various research philosophy approaches available to researchers and intend to clarify the debate on the status and nature of social science and research by discussing alternative positions and exploring the implications for different choices when establishing a research design process. The chapter then expands on issues and debates common to many of the approaches and concludes with focusing on explaining and justifying the approach chosen for this research programme by the researcher.

4.1.1 Ontology

The ontology is related to the nature of the truth in the world. This can be subjective or objective and explained as "assumptions that we make the nature of reality" (Easterby-Smith et al., 2004). According to Meredith et al. (1989), there are two major dimensions which govern the philosophical assumptions in research. The first is a rational/existential dimension, which defines whether there is just one reality and independent to the researcher. The second is a subjective dimension according to which the reality is socially constructed. Therefore, the main ontologies in research philosophy are (Easterby-Smith et al., 2004; Scholarios, 2005; Meredith et al.,1989):

- Objective ontology (physical sciences approach; deals with facts, causality, fundamental laws, reductionism, measurement and objective reality; the truth holds regardless of who the observer is; aim is to discover what is there);

- Subjective ontology (constructed; the nature of what is there is not solid but shifting; truth depends on who establishes it and facts are all human creations; aim is to understand people's interpretations and perceptions).

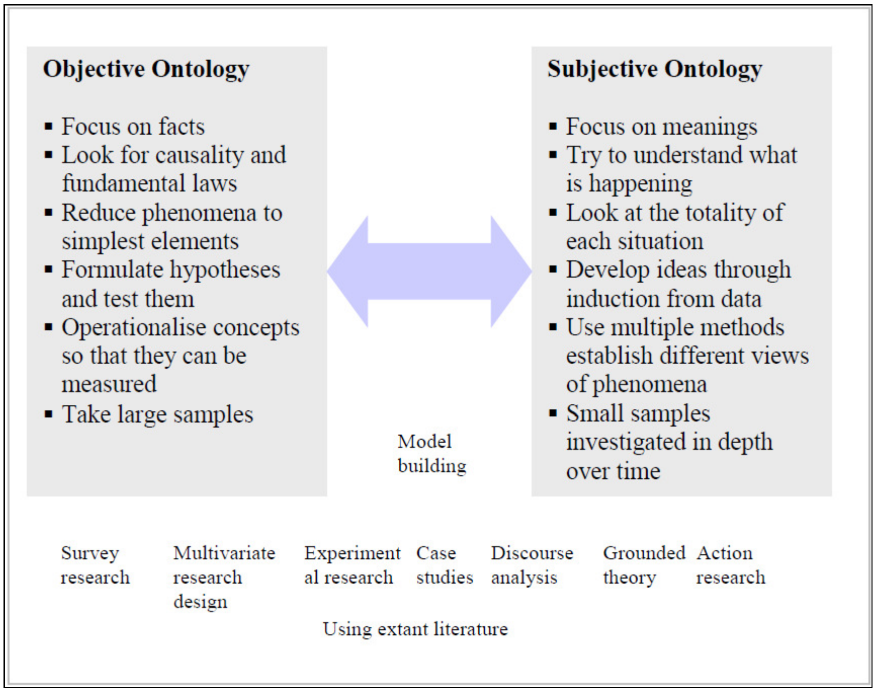

Figure 4.3 - Choice of research methods related to ontology (Beech, 2005)

4.1.2 Epistemology

Epistemology is a theoretical framework through which the researcher sees the nature of the reality in the world. The researcher looks at social world issues from different prospectives he gained through his/her background, education, personal and professional experiences. Therefore, it is a "general set of assumptions about the best ways of inquiring into the nature of the world" (Easterby-Smith et al., 2004).

There are three main reasons why an understanding of these paradigms is important (Easterby-Smith et al, 1991):

- it clarifies the research design;
- the knowledge of the paradigm philosophy helps the researcher to recognise which research design may be suitable and which may not;

- the knowledge of the paradigm philosophy helps the researcher to identify and create research designs that may be outside the researcher's experience.
Christie et al. (2000) proved how a theoretical paradigm is the underlying basis that is used to construct a scientific investigation. It is a collection of logically held together assumptions, concepts, and propositions that governs and drives thinking and research.
There are four key epistemologies / paradigms in social sciences within which researches can be conducted are:

- Positivism
- Interpretivism / Social Constructionism / Phenomenological Approach
- Critical realism / Relativism
- Action Research

To this regard, there are different philosophical arguments amongst researchers. According to the researcher's "views of the world" and to the type of research to be carried out, at the beginning of the study he/she chooses an appropriate philosophical paradigm which will determine the type of research design and therefore it will govern the research methods and techniques utilised during the study. The following sections aim to give an overview of the most important features of each of these paradigms.

4.1.2.1 Positivism

The positivistic approach, often (but not always) identified as a quantitative-type of research, assumes that the subject under examination can be measured objectively rather than being described and analysed subjectively – through sensation, reflection or intuition. (Remenyi et al., 1998). The researcher is external from the world being investigated and is objective and value free. Positivism seeks for causal explanations and fundamental laws, and, in general, it reduces the whole into its simplest possible elements in order to facilitate the analysis (Easterby-Smith, 1991).

The findings of a positivistic research in general can be applied "universally". In the type of paradigm, also called "scientific empirical method", usually quantitative research methods are employed in an attempt to establish general laws or principles. Such a scientific approach is often termed homothetic and assumes social reality is objective and external to the individual. Positivism is an approach which seeks to apply the natural science model of research to investigations of the social world. It is based on the assumption that there are pattern and regularities, causes and consequences in the social world, just as there are in the natural world. These patterns and regularities are seen as having their own existence. For the positivists, the aim of social research is to discover the patterns and regularities of

the social world by using the kinds of scientific methods used to such good effect in the natural sciences (Denscombe, 2004).
The positivistic approach is characterised by the features summarised in figure 4.4.

- independence:	the observer is independent from what is being observed;
- value-freedom:	the researcher's values do not interfere with the results or with the interpretation of the results;
- causality:	the aim is to identify the causal explanations and the fundamental laws;
- hypothetico-deductive:	proposing hypotheses and deducting what observations and analyses are required to prove them;
- operationalism:	needs to operationalise so that facts can be measured quantitatively;
- reductionism:	reduce a problem to its simplest parts;
- generalisation:	it is necessary to select samples of sufficient size in order to generalise;
- cross-sectional analysis:	comparison of variations across samples.

Fig. 4.4 – Main features of the phenomenological paradigms
(adapted from Easterby-Smith et al., 2004 - and Scholarios, 2005)

4.1.2.2 Interpretativism

The main point of interpretativism (also called "social constructionism" or "phenomenology") is the idea that reality is socially and subjectively constructed rather than objectively determined. This paradigm has arisen during the last half century in reaction to the application of the positivistic approach to the social sciences and originates from the view that the world and reality are not objective and exterior, but they are subjective and given meaning by people. The task of the researcher should not be to gather facts and data and measure how often certain patterns occur, but to analyse the different constructions and meanings that people place upon their experience (Easterby and Smith, 1991).

The naturalistic phenomenological approach to research emphasises the importance of the subjective experience of individuals, with focus on qualitative analysis. Social reality is regarded as a creation of individual consciousness, with the meaning and the evaluation of events seen as a personal and subjective construction (Blaxter et al, 2001). Phenomenology it is not mainly concerned with explaining the causes of things but tries, instead, to provide a description of how things are experienced by those involved (Denscombe, 2004). Phenomenological descriptions are not concerned with what is happening as how the events

are interpreted by those involved. Interpretivism generally starts from data rather than a literature based theory or hypotheses to be tested out. Interpretivist researchers look at organisations in depth and generally appoint to extensive conversations, observations and secondary data analysis such as company documents and reports in order to overcome generalisability critiques (Easterby-Smith et al., 2004).
However, interpretivist researchers engage with a deeper understanding of meanings in data analysis rather than aiming to generalise things. Interpretivist paradigm intends to deal with different contexts through sense making rather than objective real world.

4.1.2.3 Differences between the Positivistic and Interpretativistic Paradigms

Positivism and interpretativism are the main philosophical paradigms and, since they represent very distinctive and almost opposite views of the world, they are often matter of debates and antithesis between researchers. The central assumption of a non-positivistic research is that the researcher should be concerned with understanding the phenomena in depth and that the understanding should result from attempting to find tentative answers to questions such as “What?”, “Why?” and “How?”.

Phenomenology infers that such an understanding results from using methods other than measurement, i.e. subjective interpretation, unlike the assumptions in positivism, which is ultimately concerned with answering the questions “How many?” or “How much?”, very often (but not always, as already mentioned) in a quantitative way (Remenyi et al., 1998).
The main differences between positivism and phenomenological researches are summarized in figure 4.5.

POSITIVISM RESEARCH	***PHENOMENOLOGICAL RESEARCH***
- Objectivity	- Subjectivity
- Analysis	- Description
- Measurement	- Interpretation
- Structure	- Agency
- Representative	- Not representative

Figure 4.5 - Differences between positivism and phenomenological researches (Denscombe, 2004)

Figure 4.6 highlights more in details the key features of the positivistic and the phenomenological paradigms.

	Positivistic Paradigm	Phenomenological Paradigm
Basic beliefs	The world is external and objective Observer is independent Science is value-free	The world is socially constructed and subjective Observer is part of what is observed Science is driven by human interests
Researcher should	Focus on facts Look for causality and fundamental laws Reduce phenomena to simplest elements Formulate hypotheses and then test them	Focus on meanings Try to understand what is happening Look at the totality of each situation Develop ideas through induction from data
Preferred methods include	Operationalising concepts so that they can be measured Taking large samples	Using multiple methods to establish different views of phenomena Small samples investigated in depth or over time

Figure 4.6 - Comparison between positivist and phenomenological Paradigms

4.1.2.4 Critical Realism

In scientific researches, sometimes it is not always possible to follow a pure positivistic or phenomenological stance. The critical realist paradigm (also called "relativism") represents a valid alternative to the positivistic and phenomenological positions and can be "seen as useful compromise which can combine the strengths and avoid the limitations of positivist and interpretivist paradigms" even though it has its own strengths and weaknesses too. The main characteristic of critical realism is represented by the fact that it recognises the value of using multiple sources of data and perspectives (Easterby-Smith et al., 2004).

Figure 4.7 summarises the main distinctions between positivist, interpretivist and critical realist paradigms regarding the interpretation of the nature of truth and their general approach to perform research. As mentioned earlier, pure positivist and pure interpretivist epistemologies have almost opposed views, whereas the critical realist stance occupies a position somewhere in between the two opposite poles.

Elements	**Positivism**	**Critical realism**	**Interpretivism**
Truth	Is determined through verification of predictions	Requires consensus between different viewpoints	Depends on who establishes it
Facts	Concrete	Concrete but cannot be accessed directly	All human creations
Aims	Discovery	Exposure	Invention
Starting points	Formulation of explicit hypotheses which guide research	Suppositions/ Research Questions	Meanings/ Research questions
Research position (goal investigation)	Prescriptive, causal, deductive, theory confirming, ungrounded	Exploratory, descriptive, theory building, inductive, analytical	descriptive
Direction of research inquiry	Measurement and analysis of causal relationships between variables that are generalisable across tome and context	Development of idiographic knowledge based social experiences such as human ideas, beliefs, perceptions, values etc.	Development of idiographic knowledge based social experiences such as human ideas, beliefs, perceptions, values etc.
Designs	Experiment, survey	Triangulation, case study, convergent interviewing	Reflexivity, interviews, participant observation
Methodology	Outcome oriented, verification oriented	Process oriented, discovery oriented	Observation, process oriented
Techniques	Measurement	Survey	Conversation
Sample size	Large	Small	Very small
Data collection	Structured	Semi-structured, unstructured	Unstructured
Hardware, software	Questionnaires, statistical software programs	Tape recorders, interview guides, transcripts, qualitative software programs, visual methods	Tape recorders, interview guides, transcripts, qualitative software programs, visual methods
Type of data gathered	Replicable, discrete elements, statistical	Information-rich, contextual, non-statistical	Information-rich, contextual, non-statistical, somewhat subjective reality
Interview questions	Mainly closed with limited probing	Open with probing	Very open
Interaction of interviewer and phenomenon	Independent and value-free, a one way mirror	Mutually interactive but controlled by triangulating data, an open window	Passionate participant, transformative intellectual
Respondent's perspective	Emphasis on outsider's perspective and being distanced from data	Emphasis on the insider's perspective	Emphasis on outsider's perspective and being distanced from data
Information per respondent	Varies (specific to question)	extensive (broader question)	extensive
Analysis/ Interpretation	Verification/ falsification	Probability	Sense-making
Type of data analysis	Objective, value-free, statistical methods	Non-statistical, triangulation	Value-loaded, non-statistical
Causality	Cause-effect relations	Causal tendencies, generative mechanisms	Not addressed
Outcomes	Causality	Correlation	Understanding
Judgement of research quality	External validity and reliability are critical	Construct validity is important	Credibility, transferability, dependability, and confirmability

Figure 4.7 - Ontologies and epistemologies in social science research (adapted from Denzin and Lincoln, 2000 - Easterby-Smith et al., 2004)

Figure 4.8 summarises some of general research quality criteria for the positivistic, interpretativist and critical realist positions.

	Viewpoint Positivist	 Critical Realist	 Interpretivist
Validity	Do the measures correspond closely to reality?	Have a sufficient number of perspectives been included?	Does the study clearly gain access to the experiences of those in the research setting?
Reliability	Will the measures yield the same results on other occasions?	Will similar observations be reached by other observers?	Is there transparency in how sense was made from the raw data?
Generalisability	To what extent does the study confirm or contradict existing findings in the same field?	What is the probability that patterns observed in the sample will be repeated in the general population?	Do the concepts and constructs derived from this study have any relevance to other settings?
Most important criterion in judgement of research quality	External validity and reliability	Construct validity	Credibility, transferability, dependability and confirmability

Figure 4.8. Research design viewpoints related to research quality (adapted from Easterby-Smith et al., 2004)

4.1.2.5 Action Research

Many research approaches developed in management do not fit into either of the above categories, and they are grouped under the heading of action research. Action research is considered to be a paradigm rather than a method because of its distinctive position among philosophical debates regarding its subjectivity and high involvement of the researcher in the research setting. Action research is a collaborative approach between the researcher and the organisation. The main idea is making an impact and change happen by being involved in the process so the situation can be researched effectively. This type of research is common in practical problems such as “Organisational Development” fields where the researcher is involved in the process actively.

Action research starts from the prospective that research should lead to change, and therefore that change should be incorporated into the research process itself. Because of the collaborative characteristics of action research, participants (the researcher and researched) are likely to learn from the process itself, and their interest may be in what happens next rather than in any formal account of the research outcomes. Very often it is worth writing up action research as a narrative, so that a record is maintained of how understanding changes developed over time (Easterby-Smith, 2002). According to Easterby-Smith (2004), the main two features which are part of an action research project are:

- the principle that the best way of learning about an organisation or social system is through attempting to change it, and this, consequently, should be the purpose of the action researcher;
- the principle that those people most likely to be affected by, or involved in, implementing these changes should be as far as possible involved in the research process itself.

The aims of action research according to Huxham and Vangen (2003) are to create tools and methods, to build up theory that relates to the implementation of policy, and to develop practice-oriented theory related to management processes.

4.1.3 Methodology

Methodology is a "combination of techniques used to enquire into a specific situation" (Easterby-Smith et al., 2004). There are three main methodologies:

- hypothetico-deductive:

it is a scientific inquiry which formulates a hypothesis that can be falsified by a test on observable data; a test that run contrary to predictions of the hypothesis is taken as a falsification of the hypothesis; a test that does not run contrary to the hypothesis confirms the theory; it is then run a test to verify how stringently they are confirmed by their predictions;

- inductive:

it is a type of reasoning which involves moving from a set of specific facts to a general conclusion; it can also be seen as a form of theory-building in which specific facts are used to create a theory that explains relationships between the facts and allows prediction of future knowledge;

- co-operative inquiry:

it emphasizes that all active participants are fully involved in research decisions as co-researchers; it creates a research cycle amongst various types of knowledge; the research process iterates these different knowledge stages at each cycle with deepening experience and knowledge of the initial proposition, or of new propositions, at every cycle.

The hypothetico-deductive methodology is generally applied within the positivist paradigm. Inductive methodology often starts with data rather than literature. Co-operative inquiry, finally, is used in action research in which there is an high level of involvement of the researcher.

4.1.4 Methods and Techniques

Methods are “individual techniques for data collection, analysis, etc.” (Easterby-Smith et al., 2004). When deciding to pursue a specific epistemology, the researcher adopts methods which are commonly used within that epistemology. Techniques and methods are the practices of research undertaken within the research philosophy framework adopted and the approach the researcher takes will impact on what he/she can see and find.
According to Beech (2005), the most important research methods are:

- statistical testing,
- experimental,
- secondary data analysis,
- interviews,
- observation, and
- participation.

Beech (2005) also outlines which are the most common research techniques, i.e.:

- survey research:

defined as a method to collect information from one or more people on an organisationally relevant construct; surveys involve methods such as questionnaires, interviews and focus groups and they are commonly used within the positivist paradigm to achieve systematic observation, interviewing and questioning thorough specific research questions with the aim of providing standardisation and consistency (Fink, 2005; Moser and Kalton, 1971; Scholarios, 2005);

- multivariate research design:

commonly used within the positivist paradigm, it is achieved through three main activities – choosing and using the proper sampling methods, measurement instruments and data analysis technique (Walsh, 2005);

- experimental research:

used to gain knowledge through the observation, reflection and experimentation; the observation gathers facts, the reflection combines them and the experimentation verifies the results of that combination (Beech, 2005);

- model building:

the main modelling techniques are cognitive maps, influence diagrams and event trees; the models are developed in relation to research questions and objectives and show the relevant variables and how those variables relate to each other; the model development activities include using graphical representations, revising and refining the framework, presenting all relevant relationships, and thinking and theorising;

- grounded theory:

it is the ability to create ideas from data and to relate them according to the models of theory in general; the researcher's knowledge, understanding and skills promote his or her generation of categories and properties into theory building (Glaser, 1992); grounded theory in research is pursued to capture the complexity of the context in which action unfolds, allowing the researcher to better understand specific issues; it is also used to the study of complex entities through its ability to produce a versatile account of organisational action in its context (Dinnie, 2005).

- case studies: used in the present research study and described in the next chapter.

4.1.5 Quantitative and Qualitative Data Collection

There are two different kinds of data collection or data analysis: "quantitative" and "qualitative". Quantitative research is concerned with the collection and analysis of data in numeric form. Emphasizing in large and representative amounts of data, and perceived as being about gathering the facts (Saunders et al., 2003).

Qualitative research, on the other hand, is concerned with the collection and analysis of information in non-numeric ways by focusing on exploring as much detail as possible and aiming to achieve depth rather than breadth (Saunders et al, 2003).

The main differences between the qualitative and quantitative methods are shown in figure 4.9.

QUALITATIVE RESEARCH	QUANTITATIVE RESEARCH
- Concerned with understanding behaviour from actors own frames of reference - Naturalistic and uncontrolled observation - Subjective - Close to the data: the insider perspective outsider - Grounded, discovery-oriented, exploratory, expansionist, descriptive, inductive - Process-oriented - Valid: real, rich, deep data - Not general: single case studies - Holistic - Assume a dynamic reality	- Seek the facts/causes of social phenomena - Non-interpretative - Obtrusive and controlled measurement - Objective - Removed form the data: the perspective - Ungrounded, verification oriented, not expansionist, hypothetic-deductive - Outcome-oriented - Reliable: hard and replicable data - General: multiple case studies - Particularistic - Assume a stable reality

Figure 4.9 - Differences between qualitative and quantitative research (Blaxter et al., 2001)

There are also similarities between qualitative and quantitative research methods as shown in figure 4.10.

QUALITATIVE RESEARCH	QUANTITATIVE RESEARCH
Similarly, qualitative research may be mostly used for testing theory, even though it is mostly used for theory generation	While quantitative research may be mostly used for testing theory, it can also be used for exploring an area and generating hypotheses and theory
Qualitative data often include quantification (e.g. statements such as more than, less than, most, as well as specific numbers)	Quantitative approaches (e.g. large scale surveys) can collect qualitative (non-numeric) data through open-ended questions

Figure 4.10 - Similarities between qualitative and quantitative research (Blaxter et al., 2001)

4.1.6 Primary and Secondary Data Collection

Another distinction related to the methods by which researchers collect information for their studies can be made between primary and secondary data collection.

Data collection is a key component of inquiry, involving multiple methods of gathering information as topics are explored and questions answered. Researchers need to be familiar with primary and secondary sources of information so that they can utilize the most relevant and appropriate resources from the vast array that are available today. Recognizing the fact that there is a limitless amount of information at hand for most researchers, it is important to understand that the kinds of data and the data collection methods vary greatly as well as the uses and organizational structures of different electronic and print media sources.

When using “primary data collection”, data, figures and information that have to be used and analyzed in the project are directly collected by the researcher, for example through measures directly taken on the place of study, through original documents that could report data collected by people involved in the project and related to the topic of the study, or through interviews to the people involved in it. When using “secondary data collection”, data and information are not directly collected by the researcher, but they are retrieved through an in-depth survey and analysis of other available and reliable sources (which practiced a primary data collection to find them) such as recent and up-to-date papers, articles, books and theses about the subject of the project (critical literature review), collected for example from libraries or from the Internet. Primary sources are often used by researchers, who spend time immersed in field studies, observations, and laboratory work. They also use critical reading strategies to make the best use of secondary resources such as a critical literature review. Each of these methods allows researchers to collect data for inquiry, and each of these methods has its own skills and strategies for finding information.

A skill that is necessary for all types of data collection is evaluating information sources. Researchers need to know how to apply predetermined criteria to information sources to judge for appropriateness, accessibility, relevancy, credibility, validity, readability and availability. They have to judge information sources against increasingly more complex criteria. Once researchers have found an information source that matches all or most of their evaluation criteria, they still need to analyze the information held within the source. This requires an ability to determine timeliness of the information, accuracy of the information compared to other sources, and bias. Although much of the evaluation process can be accomplished in a search without carefully studying the actual resource itself, determining accuracy and bias can only be done through a thorough analysis of the source content. After deciding upon a particular source of information, a researcher has to provide accurate documentation of copyright information in order to avoid claims of plagiarism.

Each of these steps requires the decision-making and cognitive skills necessary to find, evaluate and document relevant information sources. During the process of collecting data, a researcher continually asks, “Does this information answer my questions?” As questions are answered through inquiry, the researcher learns how to compare those findings to previous findings or to the answers found by others. This process helps him to check for validity and accuracy. As new information is compared to existing information, patterns are identified, anomalies noted, and areas for further study established. Unnecessary information is weeded out. The act of comparing data to the inquiry questions helps researchers to reduce and clarify information so that answers become meaningful. This process of making meaning from inquiry is an important part of experiential learning.

4.2 Selecting a Research Method

4.2.1 Research Quality Criteria

The objective of the study, throughout the research process, was to properly address the research questions through an accurate investigation. However, the researcher needed to ensure that he chose and applied the appropriate research methodology.
To this purpose, the researcher was aware of seven key research quality criteria (Easterby-Smith et al., 2004; Yin, 2003(b)) which he followed to establish his study methodology choices and to ensure reliable research outcomes. They are described in the following:

- Data:

Data represent fundamental evidence to conduct a credible quality research and to answer the research questions. As mentioned earlier, data are characterised by raw data, secondary data or data worked by using analytical techniques. The variety of data collected through the research needs to be relevant, accurate and reliable. It is then used in multiple ways, it represents the basis for the study evidence and for further development within the research, and very often it also leads to important decision making by the researcher.

- Contribution to knowledge:

Another fundamental aspect of a research study is the contribution to knowledge that it brings in terms of novelty of research and filling a gap in the relevant literature. The contribution to knowledge can, for instance, assume the form of confirmation of existing theories, extension of a theory into new areas, new conjunctions between previously separate theories or disciplines, advances in methodology, developments in the application of techniques, theoretical reflection on practice, etc… (Beech, 2005).

- Contribution to practice:

The contribution to practice is another important research quality indicator if the research is conducted mainly within the field of the applied research. In this case, the research implications and outcomes help practitioners in decision making regarding business-related issues.

- Internal validity

This criterion is related to "explanatory and causal studies" and not for "descriptive" studies. This research quality aspect refers to setting up a causal relationship in order to explain how definite circumstances lead to others.

- External validity/Generalisability:

The generalisability refers to the justification of a domain to the research outcomes that can be generalised so as to ensure credibility, especially when dealing with case studies. Critics generally believe that single cases represent a poor basis for generalising, therefore a thorough reasoning based on strong assumptions should be applied in order to test and to replicate the research findings in multiple contexts (Yin, 2003(b)).

- Construct validity:

The construct validity ensures that the proper measures to analyse and evaluate the ideas and systems under investigation are in place. For this purpose, the methods used to gather the data are, for example, multiple sources of evidence and chains of evidence.

- Reliability:

Finally, the research needs to demonstrate that the investigation procedures adopted during the study can be repeated with the same outcomes in an auditable way (Yin, 2003(b)). Therefore, the reliability criterion ensures that the research is mistake-free and bias-free.

4.2.2 Research Study Structure

An initial literature review has been carried out in order to improve the knowledge of the manufacturing processes and to gather information about maximization of production resources and methodologies within furniture SMEs. At the beginning of the study, the research activity focuses on highlighting the company's specific position and production process features and requirements - such as short batch sizes, high product flexibility, variable lead times and rapid customer response requirements, and on putting the company and the project in prospective. Then, the study further develops to investigate subjects such as implementing faster job set-up and changeover times, increasing machines available running time, reducing production lead time and throughput time by reducing work-in-progress and lead time at input, reducing rework and material waste, improving work methodologies and material flows, optimizing machines and human resources utilization and establishing manufacturing key performance indicators, all these ultimately leading to the maximization of the overall manufacturing efficiency through the introduction of specific production management techniques as part of the KTP improvement programme undertaken by the researcher at the company.

Finally, the research examines problems and solutions by analyzing specific issues occurring at the company and identifying general findings applicable within the furniture manufacturing industry from the results of the analysis carried out.

4.2.3 Research Study Design

Research design has been defined as "the logical sequence that connects the empirical data to a study's initial research questions and ultimately, to its conclusions" (Yin, 1994). Yin argues that the research design has 5 main components:

- a research question,
- its propositions,
- its units of analysis,
- the logic linking the data to the propositions, and
- the criteria for interpreting the findings.

The next chapters will outline in details the research design approaches selected also according to the above criteria by the researcher as far as ontology, epistemology, methodology, methods and techniques are concerned and it will give a thorough explanation of the choices made.

4.2.3.1 Research Study Questions

The broad research question of this research study can be summarised as follows:

- How can manufacturing processes be optimised and measured within woodworking SMEs?

In order to answer the broad research question, further research questions need to be developed and addressed starting from the context of the host company and then, through proper reasoning, moving towards generalising within the wider field of the woodworking SMEs industry:

- *What are the key production-related activities that are carried out?*
- *What is the aim and key focus of the manufacturing processes?*
- *What manufacturing control tools, techniques and methods are currently being employed?*
- *Which specific manufacturing control tools can be adopted in order to optimise the production processes?*
- *What possible improvements can the implementation of innovative control techniques and methods bring to the production processes?*
- *How is it possible to implement innovative production control methods and techniques?*

The research project allowed the implementation of changes and improvements within different production areas of the business in order to maximize the overall manufacturing efficiency. As mentioned earlier, the study then investigated problems and solutions by examining specific issues occurred at the company and identifying general findings applicable within the furniture production sector from the results of the analysis conducted. Therefore, although this research work is focused on a single manufacturing organization, the academic study is in depth and the results have more general applicability within the furniture manufacturing sector, the company being a case study representative of a typical furniture manufacturing SME within the United Kingdom. Being employed on a full-time basis with the company and carrying out this research as a KTP associate provided the researcher with a unique chance to study more in depth the opportunities and the issues related to the measurement and the achievement of manufacturing processes optimization within the furniture SMEs industry.

4.2.3.2 Research Study Philosophy Approach

Before selecting the most suitable research design it is important to select a philosophical paradigm within which the research will be conducted. Choosing a research paradigm involves first the selection of a philosophical stance. According to Mendibil (2003) and Beech (2005), there are some main drivers that influence the choice of the research paradigm, i.e. the nature of the phenomena under study and the type of output required. The researcher is then expected to justify his/her approach. The researcher then chooses and explains his/her personal preferences/styles and philosophical assumptions and, finally, he/she should clarify his/her knowledge claims.

4.2.3.2.1 Ontology

The researcher positions his vision of the world in a “subjective” ontology, where reality is constructed, truth depends on who establishes it, facts are all human creations, the nature of what is there is not solid but “shifting”, and the main aim is to understand people’s interpretations and perceptions.

Moreover, the researcher believes that this is the most appropriate ontology in this kind of engineering research, where, as described above, the focus is on trying to understand what is happening (as-is situation), looking at the totality of the analysed situation, developing ideas, hypotheses and theories from observation, understanding and interpretation of samples of data collected over a period of time, and using multiple methods to establish different views of phenomena.

4.2.3.2.2 Epistemology

The researcher's vision in terms of ideal epistemology to adopt in order to bring an effective contribution to knowledge to the scientific world and to address properly the research questions of this study reflects the features of the "action research".

As described above, action research refers to a collaborative approach between the researcher and an organisation. The main idea is making an impact and change happen by being involved in the process so that the situation can be investigated and improved in an effective manner. This type of research is common in practical problems and fields where the researcher is involved in the process actively.

In this approach, research should lead to change, and therefore that change should be incorporated into the research process itself. Because of the collaborative features of action research, participants (the researcher and researched) are likely to learn from the process itself, and their main interest is in what happens next rather than in any formal account of research findings.

The researcher believes that this research, being a study related to the typical research activities of a KTP programme carried out in a technical and management engineering environment as described above, follows the epistemological key steps of an action research methodology conducted from a subjective ontological perspective.

As stated above the research project forms part of a Knowledge Transfer Partnership (KTP) programme which adheres to a certain structure. In the case of a KTP programme the paradigm and research methods are decided by the very nature of the programme. The KTP projects are government funded research programmes which aim to help a company on a project with strategic importance. The KTP associate, who acts as a change agent (researcher), is placed in the company. The associate carries out work usually in the form of analysis which is then fed back to the company during daily meetings. An external advisor attends quarterly meetings to ensure the structure of the programme is maintained. The meetings discuss the analysis carried out and future action plans are agreed regarding the strategic development of the company. The associate is often heavily involved in the implementation of these actions. During subsequent meetings the implementation is evaluated. The associate then reflects on the change process and the impact on the company.

To reinforce the researcher's philosophical choice of the action research as ideal paradigm for his vision of the scientific world and for this particular type of research as described above, in figure 4.11 are highlighted the 10 main concepts of knowledge generation through an action research programme as presented by Gummesson (2000), who refers to action research within organisations also as management "action science":

1	Action scientists take action. The concept of action is reserved for the situations in which researchers assume the role of change agents of the processes and events they are simultaneously studying.
2	Action science has dual goals: both to contribute to the client and to contribute to science. They must contribute to the general and theoretical developments in business disciplines. This requires them to juxtapose their findings to previous research and literature and disseminate them through reports, articles and lectures.
3	Action Science is interactive; it requires co-operation between researchers and client personnel and continuous adjustments to new information and new events. Those involved – the researchers and the organisation's personnel – solve problems and learn from each other and develop their competence. The interpretation leads to conclusions and recommendations that in turn lead to decisions and action.
4	The understanding developed during and action science project aims at being holistic, recognising complexities. The action scientist must focus on the totality of a problem, but still make it simple enough to engage the people involved
5	Action science is applicable to the understanding, planning and implementation of change in business firms and other organisations. Change processes are often complex, influenced by a multitude of factors that are interconnected in seemingly chaotic patterns; verbal and non verbal-cues abound and the informal is as important as the formal. Being a resident in the organisation and an actor on stage gives the researcher a unique access to change processes
6	It is essential to understand the ethical framework and the values and norms within which action science is used in a particular project. Deciding what norms should govern the research depends on the purpose of the project. Action science can also prompt the changing values and norms as the learning process of the project proceeds.
7	Action science can include all types of data-generating methods but requires the total involvement of the researcher. To understand the nature of action science, it is necessary to examine other methods of access. Qualitative, informal, in depth interviews and the ethnographic methods of observation and participation are also important as part of action science. A variety of existing material as well as quantitative survey techniques and other statistical methods may also be useful. Action science adds to the dimension of the researchers who become active participants influencing the process under study, they become change agents.
8	Constructively applied pre-understanding of the corporate environment and the conditions business is essential. This pre-understanding can be based both on firsthand understanding through reports and other intermediaries. Pre-understanding is a resource to be used when called for, not a filter to bias an investigation.
9	Management action science should preferably be conducted in real time, but retrospective action science is also an option. We have however a wealth of information stored in the minds of people who have lived through important and often dramatic changes. These authors had privileged access to events that no scholar could ever dream of attaining from a university position
10	The management action science paradigm requires its own quality criteria. Action science should be governed by the hermeneutic paradigm, although elements from the positivist paradigm may be included. Management action science cannot be evaluated by the same criteria that currently dominate research at most business schools and other research institutions.

Figure 4.11 – The 10 main concepts of action research (according to Gummesson, 2000)

Figure 4.12 shows the similarity between the cyclical nature of an action research programme (first from the top) and the model of this specific research programme (second from the top).

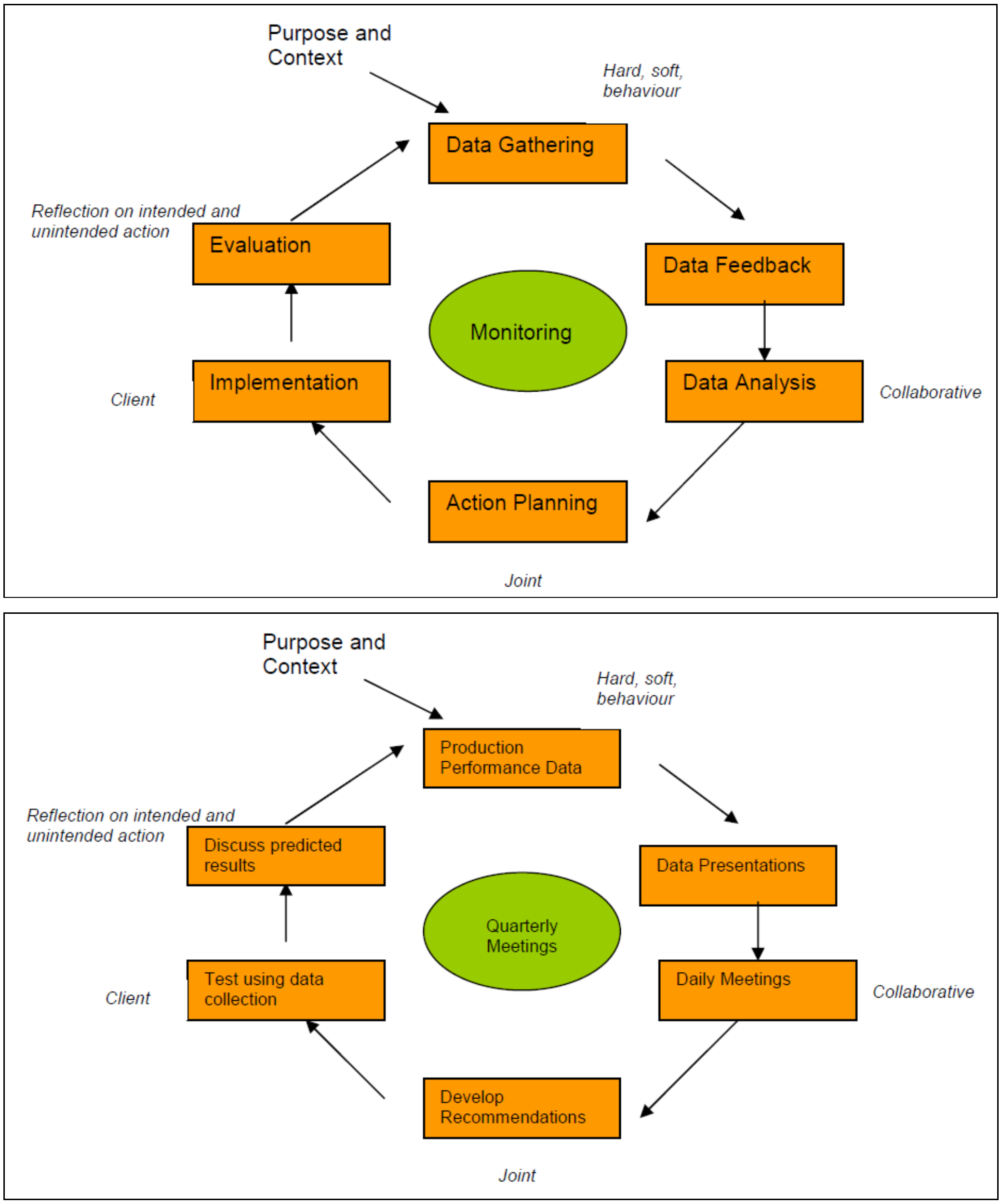

Figure 4.12 - Similarity between the action research model and this research programme

By comparing the characteristics of a KTP project with the features of an action research programme as described by Gummesson (2000) and by the figures above, it is possible to understand how this manufacturing improvement programme represents an excellent example of action research and how it perfectly fits the characteristics and goals of an action research framework in terms of investigation (data collection and feedback), analysis, action planning, implementation of change, evaluation, monitoring, and overall generation of knowledge. Hence, the researcher believes that the action research philosophical assumption, since it is closely related to the very nature of the research programme carried out and it reflects his views of the scientific world in terms of effective manner to bring a contribution to knowledge, will successfully affect the achievement of the objectives of the research study. Figure 4.13 shows that it is possible to group different epistemologies according to ontological propositions "objective vs. subjective" and the level of participation of the researcher to the research process "involved vs. independent". In particular, the figure illustrates the researcher's choice of epistemology (action research) considering the ontology position (subjective) which was justified in the previous section.

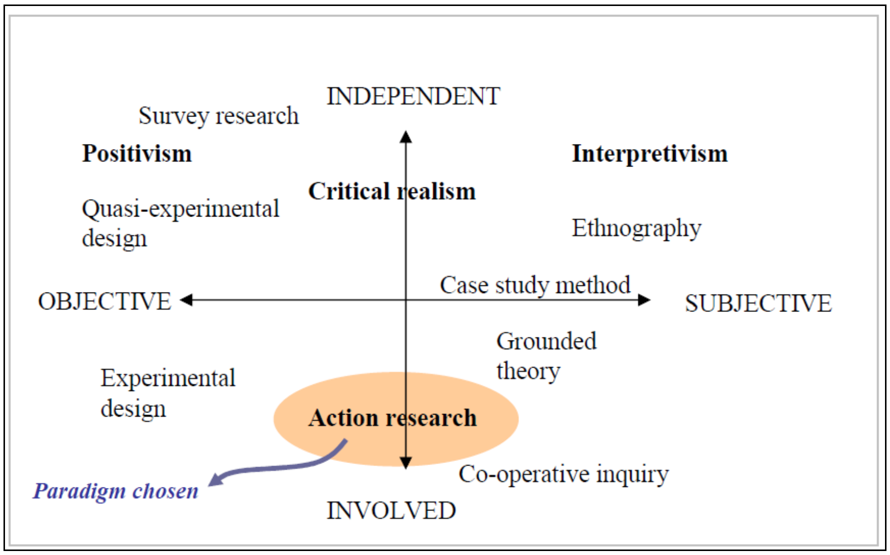

Figure 4.13 - Paradigm choice for this study (adapted from Easterby-Smith et al., 2004)

4.2.3.2.3 Methodology

Due to the high level of involvement of the researcher in the study, he believes that the ideal methodology approach is represented by the "co-operative inquiry" due to its very nature, which consists in concentrating the efforts of the research "with" rather than "on" people. It emphasizes that all active participants are fully involved in research decisions as co-researchers. According to Heron, cooperative inquiry creates a research cycle amongst 4 different types of knowledge:

- stage 1: propositional knowing - as in contemporary science, this is the first reflection phase that determines topics and methods of inquiry;

- stage 2: practical knowing – it is the knowledge that comes with actually doing what it is proposed; this is the first action phase, usually within the research group, that tests the agreed actions, records outcomes from the testing and observes if the actions conform to the original ideas from the first stage;

- stage 3: experiential knowing – it is the feedback received in real time about the interaction with the larger world; this is a second action phase, usually by individuals in their everyday life outside the research group, where the experiences and the consequences of the new inquiries in action generate new feelings and awareness. In this stage, the experiences may lead to new fields, actions and insights that depart from the original ideas;

- stage 4: presentational knowing – this is the artistic rehearsal process through which new practices are crafted; this is a second reflection phase when, in the group, co-researchers reflect on their experiences and on the data collected during the second and third stage. Now they may re-frame the original ideas and amend inquiry procedures. In this stage, co-researchers also decide whether to proceed to further cycles in the inquiry process, in which case they start their investigation again from propositional knowing. This stage involves developing new images and ways of acting.

The research process iterates these four stages at each cycle with deeper and deeper experience and knowledge of the initial proposition, or of new propositions, at every cycle.

4.2.3.2.4 Methods and Techniques

Within the action research paradigm, the researcher adopted research methods such as "participation" and "observation", using "case study" as main research technique. In particular, case study is the preferred method when he investigated the "how" research questions of the study, since he had slight control over the events and the focus was on a contemporary phenomenon surrounded by some real-life context. Case study method allowed the researcher to keep the holistic and significant characteristics of real-life events. Case studies are, in general, applied to topics such as "decisions, individuals, organisations, processes, programs, institutions and events" (Yin, 2003(a)).

Case studies are empirical investigations which aim to:

- investigate a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident;
- cope with the technically distinctive situation in which there are more variables of interest than data points;
- relies on multiple sources of evidence, with data needing to converge in a triangulating fashion;
- benefits from the prior development of theoretical propositions to guide data collection and analysis (Yin, 2003(a)).

For these reasons, the researcher particularly focused on the case study method due the exploratory nature of the research questions and the context of the study carried out in a single host company.

4.2.3.2.5 Types of Data

Data collection is a key component of inquiry, involving multiple methods of gathering information as topics are explored and questions answered.

In this research the most relevant and appropriate source of information was represented by a "primary data collection" which was directly carried out "on the field" - in the shop floor of the company. "Primary data" is information used and analyzed in the project which was directly gathered by the researcher, for example through measures directly taken on the place of study or through original documents/interviews that allowed to retrieve data collected by the people involved in the research.

Within the chosen philosophical approach, a mix of "qualitative" and "quantitative" data has been utilised in the research, with a slight predominance of quantitative information in form of key performance indicator figures gathered in the shop floor. The research required to focus on a balanced mix of the two different approaches since the study involved exploring new areas and generating hypotheses and theories (mainly qualitative data) - according to the analysis of the "as-is" situation in the shop floor - and testing the developed theories (mainly quantitative data) - in order to verify the outcome once the implementation of the innovative manufacturing control techniques was completed. In particular, a qualitative approach proved to be very beneficial for the research purposes especially when trying to understand and analyse the "behaviour" of the operators in the shop floor from their own frame of reference, whereas a quantitative position was fundamental when validating the developed recommendations through the collection and the measurement of key performance indicators in an objective and reliable numeric form, independent from perspectives of any sort. The production improvement programme carried out at the company required some information regarding job cycle times, set-up times and changeover times to be measured and entered into the system. Some of the data used in the project were found already available in the existing technical files at the company (secondary quantitative data) and were entered into the system after having verified their accuracy. However, some data were unknown to the company technical personnel at the beginning of the research programme and were directly gathered by the researcher through time studies (primary quantitative data). As it will be explained in the next chapters, by using an accurate stopwatch, several activities (e.g. processing times, set-up times, changeover times, etc…) surrounding critical machinery in the machine shop of the factory were timed continuously over various periods of time and the data obtained accordingly averaged over various time intervals.

4.2.3.2.6 Summary of the Selected Research Design

Researchers generally follow a specific route when selecting which methods to use according to the chosen research paradigm. The choice of a particular ontology and epistemology usually reflects the choice of the methods that are well established in specific research fields and are characteristic of that stance. This guides the choice process that the researcher goes through to ensure a credible and valid research philosophy approach. Figure 4.14 summarises the chosen research design (ontology, epistemology, methodology, and techniques) relevant to the philosophical stance of the researcher and to the specific type of research study carried out.

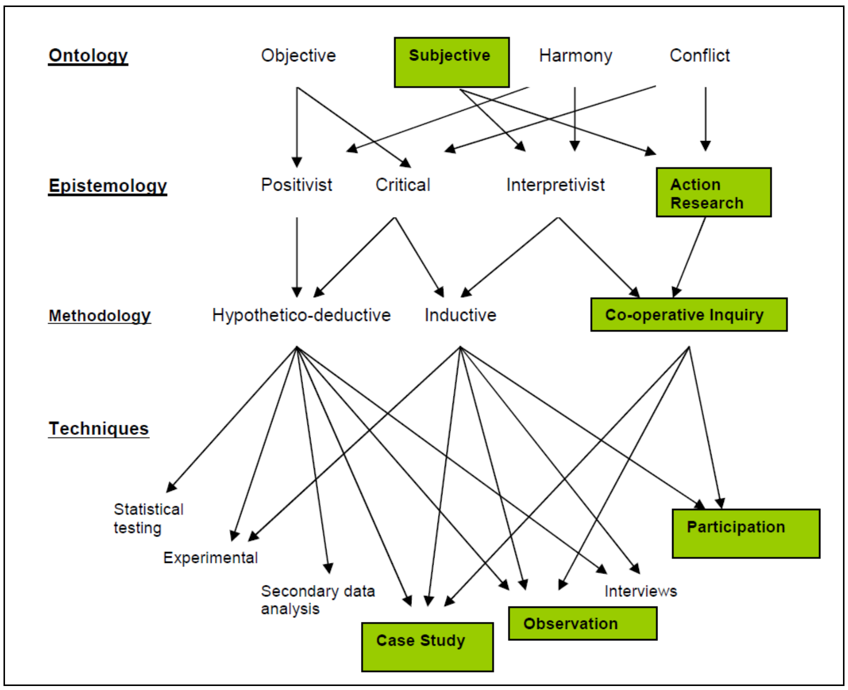

Figure 4.14 - Ontology, epistemology, methodology, and techniques chosen for this research design

Finally, it is important to highlight that credibility and robustness of the final results are indeed often disputed in action research as argued by different authors influenced by interpretivist or positivist paradigms (Huxham and Vangen, 2003). Action research is, indeed, considered to be a paradigm rather than a method because of its distinctive position among philosophical debates regarding its subjectivity and high involvement of the researcher in the research setting. It is for this reason that the researcher, during all the activities carried out at the host company in the two-year manufacturing improvement project, has always been aware of his direct participation in the research and of the high levels of subjectivity involved in action research.

5 Literature Review

As part of the Knowledge Transfer Partnership scheme, the “JRG Group” implemented an integrated improvement programme on its manufacturing processes in order to support and enhance its overall business strategy. As explained, this research aims to describe and analyse the tasks carried out and the final achievements accomplished through the implementation of the improvement programme on the manufacturing processes of the organization. The area of manufacturing process improvement is diverse and complex. Practitioners, researchers and academics have written many papers on methods and tools to achieve it presenting different views on drivers, barriers, and issues faced.

5.1 Scope and Structure of the Literature Review

To create an understanding of the subject, in the following the scope and the structure of this literature review is defined. The review aims to give from different academic and industrial perspectives a full understanding of various factors which affected the tasks performed during the improvement project and to provide an insight into various solutions implemented to solve the problems faced. In particular, the literature review initially aims to gain a definition of “manufacturing Small to Medium-sized Enterprise” (SME) since a small to medium-sized organization (“JRG Group”) operating in the manufacturing industry is the “environment” where the present research study has been carried out. The review, then, tries to gain an understanding of the single specific techniques, methods and procedures object of the various tasks of this improvement programme by taking into consideration different viewpoints and analysing the outcomes of theoretic and academic researches as well as industrial applications in order to put the study topic into its context. In particular, based on the objectives set for this research study, the investigation in the relevant literature review was scoped and structured starting the analysis by focusing on the manufacturing techniques and tools applied in the present research project:

- ISO9001:2000 Quality Management System standard;
- manufacturing Key Performance Indicators’ (KPIs) implementation;
- work method study (WMS);
- value stream mapping (VSM);
- manufacturing process computer simulation;
- Quality Function Deployment (QFD);
- Failure Mode and Effect Analysis (FMEA).

In the following chapters, this literature review considers each of these areas in turn, also highlighting the benefits they provided to the organizations that applied them into practice as stand-alone improvement methods or along with other tools as part of various integrated improvement programmes. Then, the analysis of the relevant literature investigated the results of similar integrated improvement programmes carried out in the past years in other manufacturing - and, specifically, woodworking - organizations. A high number of articles and papers on these areas were sourced mainly from the online libraries “Emerald Insight”, “ABI/INFORM Complete”, and “Elsevier Science Direct”. The search also provided a number of articles and references from the following journals: “International Journal of Operations and Production Management”, “Journal of Management Studies”, “Control Magazine”, “Decision Sciences”, “Manufacturing Engineering”, “International Journal of Agile Management Systems”, and “Logistics Management”.

The literature search found a wide perspective and deep analysis from industrial and academic points of view in the areas of “manufacturing integrated improvement programmes” and “manufacturing improvement techniques”, and, in particular, regarding the specific methodologies and tools applied during this research project. However, as it will be described later on, only very few of the improvement programmes and manufacturing improvement techniques found in literature have been applied within the woodworking and furniture sectors.

Finally, the conclusions of this literature investigation are reported and the opportunities for the objectives of this research study are highlighted.

5.2 Manufacturing Small to Medium-sized Enterprises

As explained, a “Small to Medium-sized Enterprise” (SME) is the context of the present research study and therefore it is important to define it. Generally, the basic definition of an SME as defined by the European Union commission in 2008 is any company that employs less than 250 people or “annual working unit” (micro-businesses are those with 0-9 employees, small businesses have 10-49 employees, and large businesses 250+ employees), has a turn over of less than €50 million (or a balance sheet total of less than €43 million), and is not more than 25% owned by a non-SME. Of the 3.6million SMEs within the UK, manufacturing companies make up around 9.1% of these, which amounts to somewhere in the region of 330,000 organisations nationwide. Within the UK 23% of all manufacturers are SMEs so it is clear that this is a sizeable industry sector. Common working practices that inhibit long-term planning and strategic thinking are displayed by many of these companies and are generally the product of a lack of resources, which force SMEs to focus on the short term. Often companies are limited in their activities by the financial, managerial, and human resources available. For example, most SME managers have little or no managerial backup and so they often have to handle a sudden job order or a problem that arises. The constant need to “fight fires” in this manner also makes it difficult for managers to remain committed to long-term strategic goals if they have found enough time to shift their attention from short-term issues and engage in long-term strategic planning in the first place. There is also generally a pressure to be productive within SMEs and manufacturing SMEs typically run lean type operations. Owners and employees have multiple responsibilities and perform multiple tasks. Time is a limited and, therefore, precious commodity. SME managers are under tremendous pressure to be productive all of the time. As a result, sometimes they may feel that they do not have time to experiment with new systems or to "wait" for the system to pay for itself. Instead, they must focus on activities that directly affect profitability (Hyndland and Kennedy, 2003). Moreover, SMEs are often operating within supply chains in which large companies set demanding standards and requirements. Very often a key challenge for an SME which aims to be a main contractor is that it must perform long-term planning to decide where to allocate its limited resources so as to be in a position to make the strongest technical proposals. According to Griffiths et al. (2007), SMEs engage with global industry in at least five key ways by being:

- partners to strategic alliances,
- participants in mergers and acquisitions,
- specialised suppliers to multinational companies,
- members of global informal networks, and
- involved in global electronic networks.

We can find a clear example of this situation within the woodworking industry, which is the same sector the "JRG Group" operates in: IKEA, the Swedish furniture mass distribution company, carried out a business policy where "subcontracting of production to specialized manufacturers ensured quality at a lower cost" (Mintzberg and Quinn, 1992). For these reasons, manufacturing strategy development and improvement in an SME context is an interest in today's global environment and recently it has been attracting an important amount of consideration in literature.

5.3 ISO9001:2000 Quality Management System Implementation

5.3.1 The Concept of "Quality"

Varied definitions of "quality" abound from well-known quality experts such as Juran, Crosby and Deming whom expressed "quality" as "fitness for use", "conforming to requirements", and '"predictable degree of uniformity and dependability, at low cost and suited to the market", respectively. Most recent viewpoint from the British Standard Institute (BSI) describes quality as "totality of features and characteristics of a product, service or process, which bear on its ability to satisfy a given need from the customer's viewpoint" (San, 2000). Quality and cost of manufacturing products in international business has proved some success as exemplified in many business cases in Japan. For a couple of decades, the world has watched with envy as the Japanese captured the markets with high quality products at competitive prices because of their continuous improvement of quality combined with lower cost of manufacturing (Modarress and Ansari, 2007). In the present day, there is a worldwide competition which guides quality and this makes many workers strive best to improve customer satisfaction, reduce manufacturing costs and subsequently to increase productivity (Töremen et al., 2009). Measurement of quality costs, in fact, leads to the establishment of strategic quality plan that is consistent with business goals. Philip Crosby (1979), the quality guru, said “reduced costs of quality are in fact an opportunity to increase profits without raising sales, buying new equipment, or hiring new people”.

5.3.2 Total Quality Management (TQM)

“Total Quality Management” is a management approach originated in the Japanese industry in the 1950’s and has become steadily popular in the West since the 1980’s. Total Quality is a description of the culture, attitude and organisation of a company that aims to provide, and continue to provide, its customers with products and services which satisfy their needs at best. The culture requires quality in all aspects of the company’s operations, with things being done right first time, and defects and waste eradicated from operations. Important aspects of TQM include customer driven quality, top management leadership and commitment, continuous improvement, fast response, actions based on facts, employee participation, and a TQM culture.

Increases in global competition, intensified by deregulation, have motivated organisations to adopt Total Quality Management as a strategy to meet customers’ requirements. TQM is a management philosophy of seeking excellence in all aspect of business through organisational competitiveness (Knod, Jr. and Schonberger 2001; Chase et al. 2006). TQM targets to continually improve organizations’ ability to produce and deliver goods and/or services according to customers’ requirements by better, cheaper, quicker, safer, easier processing than competitors with the participation of all employees under the leadership of top management. Brah et al., (2002) adds that TQM addresses not only the management of quality, but also, the quality of management in areas of employee empowerment and commitment by top management, not forgetting customers, employees, shareholders, competitors and even society at large. Snell and Dean (1992), Westphal et al., (1997), Withers et al., (1997) as well as Yusof and Aspinwall (2000) considered TQM as a philosophy to business management. Being a business strategy at the “top-floor”, a functional strategy at the “shop-floor” with concepts, methods, tools and techniques of its own language, TQM enabled organisations to integrate business activities into leadership, people, customer focus and satisfaction, planning, quality assurance of processes, information and analysis. Effective linking together of TQM concepts, methods, tools and techniques enhances sustainable world class performance in customer satisfaction, employee relations, operating performance and business performance (Terziovski and Samson, 1999). Improving the quality of goods/services has become one of the most important topics within companies in order to compete in the global environment. Kochan et al., (1995) concluded in a study based on companies in the USA, Japan, Canada and

Germany, that quality should be implemented not only as a set of technical engineering changes, but as part of organizational strategy change. Easton and Jarrel (1998) examined the impact of Total Quality Management (TQM) on financial performance for a sample of firms that carried out TQM implementation in the 1980's. The study indicated that corporate performance, measured by publicly available financial and accounting data, had improved for firms that had adopted TQM. Hendricks and Singhal (1996) found that firms that have won quality awards had a stronger sales growth than a sample of firms that had not won any quality awards.TQM has gained global awareness in the past two decades. In the past years an increasing demand established for manufacturers to have some sort of quality accreditation - including within the woodworking industry where the "JRG Group" operates. More and more of the large retailers started to look into their supply chain and expect the manufacturers they dealt with to have some sort of accreditation. Moreover, not only business companies have put efforts to improve the quality of their processes and final goods/services, but governments too have started to appreciate the importance of quality to international trade and the national economy. It is for these reasons that, in 1987, within the context of TQM, the European Economic Community assigned the International Standard Organization the task to create a general set of quality standards known as ISO 9000. As Raisinghani et al. explain (2005), "ISO 9000 is not a quality system in itself, but it is a set of quality standards that are defined as being necessary for manufacturers and service organizations to be effective competitors".

5.3.3 The ISO9001:2000 Standard

In the following, information and guidelines regarding the application of the ISO 9000 standards retrieved from the official International Standard Organization website (http://www.iso.org) are briefly detailed. The ISO 9000 family of standards nowadays represents an international benchmark for good quality management practices. It consists of standards and guidelines relating to quality management systems and related supporting standards. ISO 9001:2000 is the standard that provides a set of standardized requirements for a quality management system, regardless of what the user organization does, its size, or whether it is in the private, or public sector. It is the only standard in the family against which organizations can be certified – although certification is not a compulsory requirement of the standard. The ISO 9001:2000 standard provides a tried and tested framework for taking a systematic approach to managing the organization's processes so that they consistently turn out product that satisfies customers' expectations. The standard specifies what requirements a quality system must meet, but does not indicate how they should be met in any specific organization. This leaves great flexibility for implementation in different business sectors and cultures. The standard requires the organization to audit its quality system to verify that it is managing its processes effectively and it is fully in control of its activities. In addition, the organization may invite its clients to audit the quality system in order to give them confidence that the organization is capable of delivering products or services that will meet their requirements. Lastly, the organization may engage the services of an independent quality system certification body to obtain an ISO 9001:2000 certificate of conformity. This last option has proved extremely popular in the market-place because of the perceived credibility of an independent assessment. The certificate can also serve as a business reference between the organization and potential clients, especially when supplier and client are new to each other.

5.3.4 The Eight Quality Management Principles

As the official International Standard Organization website (http://www.iso.org) indicates, there are eight quality management principles on which the ISO 9000:2000 Quality Management System standard is based. These principles can be used by senior management as a framework to guide their organizations towards improved performance. In the following, the eight principles are briefly described.

Principle 1 - Customer focus: since organizations depend on their customers, they need to understand current and future customer needs, should meet customer requirements and commit to exceed customer expectations.

Principle 2 – Leadership: leaders establish unity of purpose and direction of the organization. They create and maintain the internal environment in which people can become fully involved in achieving the organization's objectives.

Principle 3 - Involvement of people: people at all levels are the essence of an organization and their full involvement enables their abilities to be used for the organization's benefit.

Principle 4 - Process approach: if activities and related resources are managed as a process, a desired result is achieved more efficiently.

Principle 5 - System approach to management: identifying, understanding and managing interrelated processes as a system contributes to the organization's effectiveness and efficiency in achieving its objectives.

Principle 6 - Continual improvement: continual improvement of the organization's overall performance should be a permanent objective of the organization.

Principle 7: Factual approach to decision making: effective decisions are based on the analysis of data and information.

Principle 8: Mutually beneficial supplier relationships: an organization and its suppliers are linked with each other and a mutually beneficial relationship enhances the ability of both to create value.

This general overview on the quality management principles underlying the ISO 9000:2000 standard shows how they can form a basis for performance improvement and organizational excellence. There are many different ways of applying them. The nature of the organization and the specific challenges it faces will determine how to implement them.

5.3.5 Benefits Achieved by Companies Applying a Quality Management System based on the ISO9001:2000 Standard

The relevant literature review analysed – Wilshaw and Dale (1990), Knock (1992), Cooper and Mitchell (1994), Pheng and Wee (2001), Wilson et al. (2003), Mulhaney et al. (2004), and Tzelepis et al. (2006) - highlighted that, in the past years, the organizations which put in place a Quality Management System based on the ISO9001:2000 standard according to the guidelines described in the previous chapter have obtained several improvements from the implementation. In particular, the main benefits regarded:

- improved operational efficiency: lower production costs because of fewer nonconforming products, less rework, lowered rejection rates, streamlined processes and fewer mistakes.
- access to new markets: some markets required ISO 9001 registration, while other markets only favoured companies with ISO 9001 certification. This was really the main objective in creating ISO9001 standard since, for example, organizations which were interested in establishing a business relationship but were geographically far from each other could compare quality without expensive audits at their locations. A uniformed standard provided them with a framework for benchmarking.

In particular, the literature review investigated highlighted that the feedback from the ISO 9001 registered companies has shown what they have accomplished as payoff from the challenge and the effort of the implementation.

- Because of the responsibilities called out in the ISO 9001 standard, organizations have often seen an increased involvement of top management with regards to the Quality Management System. This has started with the setting of the quality policy and quality goals and objectives. It has continued with management reviews looking at data from the QMS, and taking actions to make sure that quality goals were met.
- New goals have been set and continual improvement has been achieved. With the QMS in place, the organizations have been focused towards the quality goals. The management has been provided with data on a continual basis and able to see progress or lack of progress towards goals and take appropriate action. The organized, scheduled process of conducting management reviews has ensured that this evaluations have taken place. It has provided the mechanism of reviewing goals and performance against goals on a scheduled basis, and for taking action based on the evaluation.
- Goals and objectives have been adjusted based on the information collected and the organizations have become more customer driven.

- As goals focus on the customer, the organizations have spent less time focusing on individual goals of departments and more time working together to meet the customer requirements.
- Customer satisfaction has increased as goals and objectives have taken the customer needs into account. The customer requirements have been better understood as customer feedback has been sought, received and analyzed.
- Increased productivity has resulted from the initial evaluation and improvement of processes that have occurred during the implementation process and from improved training and qualification of the workforce.
- Better documentation and control of processes has led to consistency in performance, and less scrap and rework.
- Employees have had more information for troubleshooting problems on their own.
- Motivation of the workforce has increased due to the improved processes.
- Improved negotiating position with clients.
- Sales have increased substantially.
- Delivery failure rates per customer have decreased substantially.
- Customer complaints have significantly decreased.
- Training programs have enabled new staff to be productive more quickly.
- New contracts have been won.
- New business opportunities have been achieved due to access to new markets.
- Customer confidence has increased.
- Repeat business has increased.
- A number of industry accolades have been accomplished.
- All these benefits ultimately have led to financial rewards as a result of the investment in the implementation of a quality system. The case studies analysed, in fact, have shown that organizations that implemented a Quality Management System based on the ISO9001:2000 standard have realized cost savings through improved process effectiveness and efficiency and have accomplished new business opportunities which, eventually, led to much more significant financial improvements compared to those companies that have not pursued the standard

5.4 Manufacturing Key Performance Indicators Implementation

As Neely et al. (1997) explain, “a good manager keeps track of the performance of the system he or she is responsible for by means of performance measurement”, which is used to see how well managers and employees are performing their tasks and executing the various process stages. Performance indicators tell” what has to be measured and what are the control limits the actual performance should be within”. Another definition is provided by Nenadal (2008), who explains that process performance measurement is “the monitoring of agreed performance indicators to identify whether a process meets planned targets”. Neely et al. (1997) argue that traditionally performance indicators have been used to quantify the efficiency and effectiveness of actions. Globerson (1985) asserts that “the lack of well-defined performance criteria, through which performance of individuals and the organization may be evaluated, make it hard to plan and control”. Nanni et al. (1992) explain how performance measures are part of a feedback loop, which “controls operations against a specific value”. Neely et al. (1997) conclude that performance measures are an integral element of the planning and control cycle and provide “a means of capturing performance data which can be used to inform decision making”.

Turner et al. (2005) specify that, in manufacturing companies, the application of performance measures in the last decade has developed from what were traditional financial performance indicators to now include a wider range of non-financial performance metrics. In particular, in manufacturing, as Nenadal (2008) clarifies, the term performance identifies a range of concepts such as effectiveness, efficiency, productivity, yield, capability, quality, etc… which represent various dimensions of performance.

5.4.1 Key Performance Indicators in Literature: a Brief Overview

As Turner et al. (2005) pointed out, most of the existing literature covers the definition of performance measures, performance measurement system design and methods to align performance measures to strategy and guides managers in what to measure in their organizations. The literature concerning performance measurement evolved through two phases, as Ghalayini and Noble (1996) explain. The first phase started in the late 1880s and was characterized by a cost accounting orientation aimed at assisting managers in evaluating the relevant costs of operating their organizations. This approach was later modified to include some financial measures as well. However, this approach was strongly criticized since focusing only on financial measures when measuring performance tended to encourage short-term thinking (Banks and Wheelwright, 1979; Hayes and Garvin, 1982; Kaplan, 1983) and failed to measure all the factors critical to business success (Kaplan, 1983, 1984). Ghalayini and Noble (1996) then explain that the mid-1980 marked the beginning of the second phase, which was characterized by the growth of global business activities. Johnson and Kaplan (1987) underscored the need for better integrated performance measurement criticizing the traditional accounting/financial performance measures since they ignore the customer needs. McNair and Mosconi (1987) highlighted the need for the alignment of financial and non-financial measures in order to be in accordance with business strategy. Santori and Anderson (1987) stressed the importance of non-financial measures in monitoring and motivating the progress of the human factor of the organization.

5.4.2 Design of Key Performance Indicators

As Azzone et al. (1991) explain, in order to understand "where" to measure, it is necessary to understand in which part of the business value is built up and how this happens by determining the main activities through which an organization creates value.
Nenadal (2008) also clarifies that:

"the design of a performance measurement regime must cover all important processes within the company's operating framework. Some areas may have been measured in detail for some time (cycle time, scrap rates, throughput levels, etc) and a company can learn a lot by examining these measures and seeing how they are used and which ones are particularly important. Other areas may not have been measured at all. We can learn from the measured processes so that we can start to apply appropriate measures and indicators to the non-measured processes".

According to White (1996), when designing performance measurement metrics, there are two basic questions that must be answered:
- "what" will be measured?
- "how" will it be measured?

The validity, reliability, and practicality of the measure are influenced by the way in which these questions are answered. The large number of different performance measures available within the manufacturing environment indicates that there are many ways to answer these questions. For instance, as White (1996) clarifies, "the question of what to measure has traditionally been answered by focusing on cost-related measures such as labour efficiency or machine utilization. The question of how to measure has generally been answered through the accounting department's cost accounting system". As White (1996) explains, the literature about manufacturing performance measurement has emphasized that performance measurement is an important tool for making companies more competitive in the global marketplace. They argue that "performance measurement serves not only as a scorecard, but also as a compass that can indicate directions for needed improvement in a company's manufacturing activities". Jonsson and Lesshammar (1999) also clarify that it is not enough to identify what to measure and how to measure it. In fact, the measures also need to be designed so that the performance information can be successfully used. The way may differ between environments with different objectives.

5.4.3 Features of Key Performance Indicators

The performance measurement literature describes some relevant characteristics of performance measures and measurement systems. In the following the findings regarding features of organization-wide measures are summarized, highlighting at the end of the paragraph the main findings as far as the manufacturing sector is concerned. Gomes et al.

(2004) explains that, according to managers' visions, performance measurement frameworks should provide an early warning detection system indicating what has happened, diagnose the reasons for the current situation, and indicate what remedial actions should be undertaken. Jonsson and Lesshammar (1999) highlight 6 dimensions within which performance measure systems should be developed:

- Strategy: the measurement system translates the business strategies to all levels.
- Flow orientation: the measurement system integrates all activities along the supply chain.
- Internal efficiency: the measurement system allows comparison between internal functions.
- External efficiency: the system interacts with customers and measures their satisfaction.
- Improvement drivers: the measurement system is used for continuous improvement.
- Simple and dynamic: the circumstances for measurement are fast changing.

Neely et al. (1997) indicate 10 elements which characterize a "good" performance measure to consider when designing indicators:

- "Title": it should be clear and explain what the measure is without any specific jargon.
- "Purpose": the rationale underlying the measure has to be specified.
- "Relates to": the measure needs to relate to one or more the business objectives.
- "Target": it specifies the level of performance to be achieved and a time scale to achieve it.
- "Formula": the way performance is measured is fundamental since it affects how people behave.
- "Frequency": how often the indicator is recorded depends on the importance of the measure.
- "Who measures": it identifies the person responsible to collect and report the data.
- "Source of data": a consistent source of data is vital if performance is to be compared over time.
- "Who acts on the data": it specifies the person who should act on the data.
- "What do they do": it defines what to do if performance is either acceptable or unacceptable.

Neely et al. (1997) also recommend that measures should be derived from strategy, provide timely and accurate feedback, relate to specific and achievable goals, be based on quantities that can be controlled by the user, be clearly defined, be part of a closed management loop, have an explicit purpose, be based on a defined formula and source of data, employ ratios rather than absolute numbers, and use data which are automatically collected as part of a process.

Nenadal (2008) argues that the key features of any measurement regime are:

- validity: "the indicators must express what counts objectively and the results must be accepted by the users";
- completeness: the indicators must reflect all important aspects of the process performance;
- sufficient detail and accuracy: the resources spent to collect and analyse the data need to be proportionate with the value of the data provided;

- sufficient measurement frequency: the measurements need to be taken often enough to obtain a realistic picture of the system performance;
- timeliness: the process owner must have access to performance data when he needs it;
- easily understood terms: “all those being measured and all those using the measurement data should be able to explain any performance indicator”.

He concludes highlighting that “there must be enough indicators to give a comprehensive picture of performance but not so many that they overload and confuse the users of the measures”.

According to White (1996), performance measures can be classified based on the competitive capability being measured (cost; quality; flexibility; delivery reliability; speed), the data source (internal: from sources within organization; external: from sources outside organization), the data type (objective: based on perceptions; subjective: based on observable facts not involving opinion), the reference (benchmark: compares an organization with others; self-referenced: does not involve any comparison with other organizations), and the process orientation (input to some process; outcome of some process). Finally, Azzone et al. (1991) point out that, as far as time-based businesses are concerned, the main features of effective performance measurement metrics are simplicity and relevance. Simplicity means that the chosen indicators must be few, in order to keep the complexity of the system low by focusing only on critical success factors. Relevance means that the measures selected must measure time through physical indicators rather than by financial metrics.

5.4.3.1 Features of Manufacturing Key Performance Indicators

As far as manufacturing is concerned, according to Jonsson and Lesshammar (1999), a performance measurement system can be used for top management control and continuous shop-floor improvement and can be compared against internal targets or external benchmarks. They explain that a complete manufacturing performance measurement system needs to be comprehensive and cover the most critical performance dimensions of the organization. Ghalayini and Noble (1996) argued that manufacturing performance measurement systems should be dynamic, stress the importance of time as a strategic performance measure and link the areas of performance measurement to the factory shop-floor. Maskell (1991) stated that a good measurement system should be related to manufacturing strategy, include non-financial measures, vary between location, change over time, be simple and easy, give fast feedback, and aim to teach rather than to monitor. Caplice and Sheffi (1995) argued that a good manufacturing performance measurement system should be comprehensive, causally oriented, vertically integrated, horizontally integrated, internally comparable and useful. Lynch and Cross (1991) noted that good systems include the need to link operations to strategic goals, integrate financial and nonfinancial information, measure what is important to customers, motivate operations to exceed customer expectations, identify and eliminate waste, shift the focus of organisations from rigid vertical bureaucracies to more responsive, horizontal business systems, accelerate organizational learning and build a consensus for change when customer expectations shift or strategies call for the organisation to behave differently, and translate "flexibility" into specific measurement. Yurdakul (2002) and Gosselin (2005) explain that, within the manufacturing industry, dependability, time, flexibility, quality, and cost are the performance criteria which need to be considered when designing metrics:

- Dependability: it is a "measure of a company's planning and control system's effectiveness and shows the trust level in a manufacturing system" (Slack, 1991). In a dependable manufacturing environment, the right products are produced and delivered on the agreed dates with the planned quantities. Some of the performance indicators for the dependability criterion are the number of changes in a time period, the delivery performance (e.g. the percentage of quantity over or under original schedule; the differences between actual start and completion dates and scheduled start and completion dates), and the machine availability (e.g. the ratio of maintenance cost spent to prevent failures before they occur to repair cost; the percentage of machine up time).
- Time: the literature reports that about 5% of a production cycle time is spent actually making a product and during the remaining time is spent in non value-adding activities (Maskell, 1991). Production cycle time, therefore, is one of the indicators that can be used as a direct measure of time performance of a manufacturing system.
- Flexibility: it is possible to respond to the variability of the customer demand by increasing the adaptability of a manufacturing system. Typical measures of flexibility are lot size, setup time, percentage of standard, common, and unique parts, number of different parts and processes, cross-training of production personnel.
- Quality: the products manufactured need to meet the "conformance to specification" - prescribed design features and performance level. This criterion represents the organization's capability to "do things right" without making mistakes in the manufacturing system which reduces rework, scrap and waste. Indicators of quality are, for instance, related to the customer response, such as percentage of repeat sales, time between service calls, and number of complaints.
- Cost: in order to achieve a cost advantage, either resources should be obtained cheaper or they should be converted to products more efficiently than competitors. Cost per unit, for instance, can be used to measure the cost performance of a manufacturing system.

5.4.4 Main Criteria Used to Implement Manufacturing Key Performance Indicators during the Research Study

During the research study programme, in order to establish key performance indicators within the manufacturing areas of the business of the company, the SMART (Specific, Measurable, Attainable, Realistic, Time-sensitive) goal setting method has been used, amongst the other criteria highlighted in the previous paragraphs, as one of the main framework of reference against which indicators of various aspects of the production processes in place have been designed and implemented. The relevant literature analysed on the subject highlighted that goal setting, performance measurements and feedback have been proven to improve productivity (Locke and Latham, 2002). Goal setting theory and system performance studies suggest that specific and challenging goals result in a higher performance than moderate or easy achievable goals, vague goals or no goals at all (Locke and Latham, 1990). It is for these reasons that the SMART goals setting theory has been used during the integrated improvement programme conducted at the company with the aim of creating and putting in place manufacturing key performance indicators within the shop floor. Prather (2005) in his research study highlights that using SMART criteria in goal setting and performance measurements "works well when the goal is to improve an existing system about which much is known". He explains that these criteria, for instance, "fit extremely well when some aspect of the business has deviated from normality in a negative way and the task is to return that aspect to normal". It is quite easy to see how effective the use of SMART criteria can be for setting goals and measuring performance with the aim of perfecting the system. Common examples are to build sales, cut costs, and restore or increase manufacturing yield or quality in production. In each of these cases, using SMART criteria to set goals and measure the performance "works because ambiguity about the situation is minimal, and the desired outcome is to restore the system to normal operation or incremental improvements". According to Shahin and Mahbod (2007), in any organization, goals guide the organization's efforts, support the distribution of resources and focus the organization on success. Goal setting is one of the first steps an organization should complete. According to several researchers, there are many benefits in setting goals but primarily goal setting ensures that the organization gets the job done that needs to be done, when it needs to be done, by the people who need to do it, within the resources available. Shahin and Mahbod (2007) explain that key performance indicators reflect and derive from the organizational goals. They also emphasize the distinction between goals and key performance indicators: indicators measure the progress towards the achievement of certain goals and they are based on criteria that make it suitable for further analysis.

The relevant literature review highlighted that the SMART criteria are the most often referenced when organizations deal with setting goals and measuring performance.

In the following, a brief explanation is provided of the 5 SMART goal criteria against which manufacturing performance indicators have been established during the research study programme:

- Specific: goals should be detailed and as specific as possible since it is much easier to hold someone to account for their achievement.
- Measurable: goals should be clear, concrete and measurable in order to determine if objectives have been achieved. The measure may be quantitative or qualitative, but measurement should be against a standard of performance and a standard of expectation.
- Attainable: goals should be reasonable and attainable. Setting goals is a balance between a degree of attainability and challenge and aspiration.
- Realistic: goals should be realistic and result-oriented. Sometimes goals can be attainable, but not realistic in a particular working environment. Realistic goals help assessing the availability of resources and selecting proper key performance indicators.
- Time-sensitive: goals should have a time frame for completion. A time frame provides a structure and allows to monitor the progress during the 'journey' towards reaching the goal, and, ultimately, to measure the final success. It also assists in developing a realistic action plan, including setting intermediate objectives and strategies for reaching the goal.

5.4.5 Implementation of Key Performance Indicators: Steps, Drivers and Blockers

According to Bourne et al. (2000), Marr and Neely (2002), Nudurupati and Bititci (2000, 2003) and Kennerley and Neely (2003), the performance indicators are implemented through the following steps:

- Data creation: raw data captured or recorded at source.
- Data collection: collection of raw data required to measure the indicators defined.
- Data analysis: conversion of the collected raw data into useful information, in the form of trend charts, comparison charts, reports, statistical analysis, etc…
- Information distribution: communication of the information to the relevant personnel to assist the decision-making process.

According to Lewin (1947, 1951), there are two factors affecting the implementation of techniques or technology - e.g. performance indicators - in an organization, i.e. drivers and blockers. He suggests that it is necessary to decrease or eliminate the barriers before implementing and increase the drivers after implementing for a successful implementation. Bourne (2001) identified two main drivers and four blockers to drive successful implementations:

The two main drivers are:

- Top management commitment, which should be responsible for the objectives and the measurement system (Coch and French, 1948; Meekings, 1995).

- The perceived benefits arising from designing, implementing and using the performance measures (Turner et al., 2005).

The four main blockers are:

- The time and effort required.
- The difficulty of implementing the measures caused by inappropriate information being available and by wrong interpretation of the information due to the presentation format.
- Resistance to performance measurement, for instance due to fear of personal risk (Meekings, 1995) or uncertainty about the outcome of the implementation (Sayles and Straus 1966, McNurry 1973, Meekings 1995, Waddell and Sohal 1998).
- New parent company initiatives, such as removing resources necessary for performance measurement, assigning new higher priority projects, etc…

As far as manufacturing is concerned, Gomes (2004) clarifies some aspects related to the implementation and the daily measurement process highlighting that the manufacturing performance measurement should be based on information availability, reliability and responsibility. The information availability emphasizes the need for a systematic performance measurement information system, where information is not only tracked, stored and made available to the relevant personnel. Reliability includes the reliability of the manufacturing resources, the information flow obtained from the shop-floor and the marketplace. Responsibility means the responsibility of all elements of the organization, as they attempt to execute their tasks.

5.4.6 Factors for a Successful Usage of Key Performance Indicators

Eccles 1991, Davenport 1997, and Prahalad and Krishnan 2002 highlight that the success of the use of performance indicators lies in people's behaviour in using properly the information gathered. Meekings (1995) argues that making people use measures correctly not only leads to performance improvement but also becomes a vehicle for a cultural change.

According to various authors, the effectiveness of the business behaviour resulting from the performance information collected depends on several factors:

- Drive from senior management (Hudson et al., 1999; Bourne and Neely, 2000; Marchand et al., 2000; Bititci et al., 2002).
- Communicating strategy throughout the company in the form of relevant performance measures (Bourne, 2001).
- Employees using the performance information for identifying business trends (Orlikowski, 1996; Donovan, 1999; Feeny and Plant, 2000; Kennerley and Neely, 2002).
- Employees using the performance information for decision-making (Lebas and Euske, 2002).
- Employees not being resistant in using performance information (Waddell and Sohal, 1998; Battista and Verhun, 2000).

- Proper training provided for the people in using performance information (Markus, 2000).
- Empowering people in making decisions based on performance information (Schaffer and Thomson, 1992; Schein, 1996; Badham et al., 2001).
- Stimulating actions required to improve key areas (Bititci and Nudurupati, 2002).

To this regard, Sinclair and Zairi (1995), finally, point out a crucial factor to be considered during the performance indicators design, implementation and data collection stages. They argue that, since performance measuring can profoundly affect the motivation of individuals, the performance measurement system must take the human factor into consideration. It is, therefore, fundamental to consider that the performance measurement related activities must not compromise the productivity and efficiency of the employees. Also Neely et al. (1997) highlight that organization, when creating and putting in place performance measures, should always consider the behaviours that the indicators - and their values once collected or calculated - are likely to induce in workers. Systems, in fact, respond to performance measures and people tend to modify their behaviours in an attempt to ensure a positive performance outcome even if this means pursuing inappropriate courses of action. Finally, as the strategy for the company changes dynamically, based on internal and external factors, the relevant performance indicators should also be reviewed to maintain their relevance within the business strategy (Dixon et al., 1990; Bourne et al., 2000). Therefore, a performance measurement system should also include an effective mechanism for reviewing targets (Ghalayini and Noble, 1996) and a process for modifying existing and creating new measures as circumstances change (Maskell, 1991; Dixon et al., 1990; Meekings, 1995; Kennerley and Neely, 2002).

5.5 Work Study

According to Faraday (1977), the basic purpose of the "work study" is to "optimise the use of human and material resources available to an organisation". This statement sets out the objective of what the work studies aim to achieve within any organisation. A work study in the production areas allows a company to review how the available manufacturing resources are used. This helps to identify areas which are characterised by non-optimised work procedures and need improvements in order to increase the level of output produced. A work study, therefore, is set out to evaluate tasks and improve the productivity. It is important to understand what "productivity" is and how it is affected before the process can be improved. A good definition of "productivity" is "the quantitative relationship between what we produce and the resources which we use" (Faraday, 1977). This accurately describes what the work study is working towards, as it increases the level of output by maximising the resources available to the organisation. Through the increase in productivity, the company can expect to see increased profits. As a consequence, the employees' wages can be increased, which is a good incentive for everyone involved to work towards the same common goal. The various factors affecting the work study relate to physical attributes such as quality of goods and tools available, which can be easily measured and improved where necessary. They are also easily measured against cost, where the expenditure can be assessed against the gain they will produce. There are various "lines of action" to increase productivity, some of which are long term, others medium term, and some short term. This allows the company to take actions depending on how important the final objective is, with long term goals requiring considerable investment in comparison to short term goals which can often be done at very little cost. These choices are economically based, and tend to be determined based on the success of the organisation at that stage

There are various techniques in applying a work study to an organisation:

- Method Study
- Work Measurement
- Time Study
- Synthesis from Elemental Data
- Predetermined Motion Time Systems
- Analytical Estimating
- Comparative Estimating

Each of these techniques have different applications and can be chosen to be used based on what is being studied and the time and available resources to an organisation.

5.5.1 Method Study

The "method study" procedure is defined by the British Standards Institution glossary of terms as "the systematic recording and critical examination of existing and proposed ways of doing work, as a means of developing and applying easier and more effective methods and reducing costs". The method study application is a very detailed approach as it *"*involves the breakdown of an operation or procedure into component elements and their subsequent systematic analysis*"* (Faraday, 1977). This means that as all factors affecting production are examined, those with little to no influence can be eliminated while others can be improved upon. According to Faraday (1977), there is a basic analytical procedure to follow when carrying out a method study which involves six essential steps which need be fulfilled to achieve greater productivity:

- select the situation or problem to be examined;
- record relevant data about it;
- examine the recorded data;
- develop fresh ideas and approaches;
- implement new working arrangements, processes or procedures;
- maintain that new arrangement as standard practice.

At the end of these stages, all unnecessary work and procedures should be removed, while optimising only the necessary work activities which are left, therefore eliminating all waste within the system. Daniels (1997) highlights the essential simplicity of this procedure, which can be used as the basis of complex investigations. There is a great range of recording techniques available for the record stage: flow charts, travel charts, multiple activity charts, string diagrams, activity sampling charts, etc…The data collection stage serves to strengthen the development of new ideas and approaches. Daniels (1997) again explains that the basic charting and diagrammatic techniques serve as communication devices. “Most of them are also simple and training can be given to employees to allow them to record (at least in outline or draft form) the kinds of processes and activities on which they work. Even if they are not to undertake their own recording, a basic understanding of the simpler techniques allows them to communicate with support specialists who may produce the charts and diagrams and to discuss and confirm the information recorded” (Daniels, 1997). Often employees are most concerned with the part of a process they are personally involved in. “It is useful to let them see how their particular activity or job fits into a wider process and process charts are a useful means of doing this. Many of the techniques that are not aimed at the creation of ideas are aimed at the provision of information – information to inform decisions about alternative ideas, ways of working, capital investment, etc…” (Daniels, 1997).

5.5.2 Work Measurement

“Work measurement” is focused on the actions carried out by the human workforce, which is defined by the British Standards Institution as *“*the application of techniques designed to establish the time for a qualified worker to carry out a specified job at a defined level of performance*”* (Faraday, 1977). Daniels (1997) defines work measurement as a range of techniques for providing information about activity completion times, workloads, capacities, etc…with wide applicability within the planning and monitoring areas. This technique is used to set a benchmark for the time taken to carry out an activity, which is usually based upon experience. Researches show that this is not the best way to set target times as each process can have differences dependant on the type of work being carried out. A work measurement study provides the data required to set reasonable target times for workers to aim for. The target times need to be based upon an adequate performance level and relate to the method study carried out in order to determine suitable labour requirements against the actual labour involved. The measurement also helps to set incentives as well as providing data for future costing and labour requirements. In a productivity improvement programme, Daniels (1977) argues, work measurement techniques “can be used by particular groups to assist in their own determination and evaluation of alternative working patterns and procedures. If used in this way, at the request of work groups or teams, it can be established as a supporting rather than damaging agent". Some of the techniques, as Daniels (1997) clarifies, are specifically designed to provide data about group activity, work load and performance. They may be seen by the workforce as less 'threatening' than those which are aimed at individual measurement. Daniels (1977) also explains that work measurement techniques, unfortunately, have "often been linked to payment systems and individual performance measures have been treated with antagonism by many workforces, with the measured times being incorporated into the wage negotiation system". Daniels (1997), again, explains that work measurement, with results expressed in time units, is important since "time is a basic resource that incurs both actual cost (from what is done in the time and from 'overhead' charges that accrue in a time period) and opportunity cost (what could have been done in the time)". However, as Daniels (1997) points out, "work does not use up all the time of an organization". In fact, just as much, if not more, is used by non-work. The non-work time is taken up by various delays, often in the form of temporary storage". Very often it is interesting and beneficial to undertake measurement of not only the work content of a job, but also the overall throughput time or lead-time from order to delivery (sum of the work time and the non-work time) and to measure one as a percentage of the other. The size of the resulting figures may offer strong motivation for improvement.

5.5.3 Time Study

A "time study" is the original technique the work measurement is based upon and looks at the work involved directly as the actions are carried out. This technique is used mainly to monitor and measure repetitive tasks, as opposed to one off activities. There are four important aspects which the time study must fulfil. The first is an accurate definition on the actions under investigation. This means that clear definitions of who should carry out each task as well as when an activity starts and stops are needed. The time study also takes into account the materials and tools required to carry out each individual activity. Suitable recording methods for observers also need to be undertaken which allow times to be recorded while watching workers carry out each activity. The next stage is characterised by defining what are considered standard rates of work. Finally, an adequate rest period associated with each work activity is required. Another important aspect is represented by the time scale to be used. Seconds, although well established, are sometimes difficult to work with as certain activities take longer periods of times and value of times in seconds get larger. This leads to alternatives being considered such as "decimal-minutes" and "decimal-hours". The unit of measure chosen needs to be used throughout the study and to be clearly defined and understood by all personnel involved in the work study being carried out.

5.5.4 Synthesis and Element Data

Another technique used in work study is represented by "synthesis and elemental data" as opposed to the time study, which is often applicable in many manufacturing situations. These types of data are acquired when processing techniques are not always repetitive, however they may have certain aspects which are repeated throughout many processes. To gather the required data can take a long time, and the best process to use is to measure all techniques and processes in order to choose which are most common throughout the manufacture of the products. There are two key issues which require to be addressed: "the work measurement studies need to be designed to produce them" (Faraday, 1977) and also that "the results are recorded in a way which ensures complete understanding and facilitates application" (Faraday, 1977). This means that all processes should be assessed and produce results available for analysis, no matter how small the task may be. Generally, although the time study is quicker to carry out and requires less data, the synthesis is a cheaper version to implement into a system.

5.5.5 Predetermined Motion Time Systems

The time study evolved to the formation of a set of factors which allow the formation of standard times for different actions, which are known as "predetermined motion time systems". The aims of these are to reduce the need for constant re-evaluation of time analysis, and to develop a technique which allows further measurement to be determined. The idea is that there is a set time standard for carrying out a certain simple operation. This standard is then adjusted based on a variety of different factors such as the component weight, the control and direction, etc... These factors are difficulties which prolong the length of any motion, and lengthen the original standard time. These are judged by the observer and applied accordingly to help set times and targets. The most evolved concept of this type of work in use is the "methods-time measurement", which is widely used.

5.5.6 Analytical Estimating

So far the work study techniques have dealt with repetitive tasks, however not all cases involve repetition of work. A technique used to measure non-repetitive work is called "analytical estimating" and is used to "enable basic times to be synthesized for all the elements involved" (Faraday, 1977). According to this technique, the process is broken down to accommodate various job elements and to analyse these individually. This type of analysis is carried out by someone who understands the processes involved and which elements affect the task, ideally a skilled tradesman. Using a skilled tradesman allows greater understanding of what is actually going on and provides better data for the analysis with breakdown of elements being much more precise. When recording times, the conditions they were recorded under are also noted in order to give evidence when looking to estimate further times. For instance, such conditions could be a lack of proper tools or damaged materials which both require additional work.

5.5.7 Comparative Estimating

Using the technique of analytical estimating can cause problems, since there must be an estimator for a group of around 15 people on permanent basis. One way of overcoming this issue is to use another technique called “comparative estimating”, which is used when an evaluation of the job is carried out by a comparison with *“*the work in a series of similar job benchmarks*”* (Faraday, 1977). The idea is that there are a series of jobs for which times have been assessed and assigned. When a new job occurs, these times are then used to benchmark against and assign a band which they can operate within. Although it is a limiting process, there are advantages of using this technique. This may be cheaper to carry out compared with analytical estimating and also gathering data requires much less time once the initial bank of bands has been set up. This allows faster implementation once new jobs are created, although slightly reduces accuracy.

5.6 Value Stream Mapping of the Manufacturing Processes

5.6.1 Origins and Definitions of Value Stream Mapping

Also called a material and information flow analysis (MIFA), the “Value Stream Mapping” (VSM) is a technique used to graphically display and analyse all the relevant data about the manufacturing processes in place within an organization. Value stream mapping helped to provide and interpret information which was fundamental to properly set up and perform the computer simulation task during the research programme. The VSM tool was selected as a sensible tool to visualise the production processes in place at JRG Group since, as Lasa et al. (2008) explain, it is “a functional method aimed at recognising production systems and supports the redesigning of a manufacturing system”. According to Hines et al. (1998), value stream mapping has its origins in industrial engineering, which comprises a group of techniques that are used to “eliminate from the workplace waste, inconsistencies and irrationalities, and provide high-quality goods and services easily, quickly and inexpensively”. In particular, they explain that value stream mapping was initially developed in 1995 "to help researchers or practitioners to identify waste in individual value streams and, hence, find an appropriate route to its removal". The approach requires the researcher to identify the severity of a series of wastes within a manufacturing environment and to choose, apply and analyze the output from a series of appropriate changes to the system. They carry on clarifying that, “instead of comparing a firm's work processes with others, VSM is a type of specific process benchmarking where the initial performance of a particular process is not externally compared but is internally compared with how good that process itself could be". In other words, the value adding and wasteful activities are compared in order to picture how the process could look like if a percentage of the waste was removed.

Other definitions, scopes and uses of VSM were found in the relevant literature. Hines and Rich (1997) describe value stream as a collection of all actions value added as well as non-value added that are required to bring a product or a group of products that use the same resources through the main flows, from raw material to the hands of customers. Tapping and Shuker (2003) explain that a value stream consists of everything including the non-value added activities and provides a visual view of what elements of the process the customer is willing to pay for. Voelkel and Chapman (2003) define VSM as ''the simple process of directly observing the flows of information and materials as they occur, summarizing them visually, and then envisioning a future state with much better performance''. Jones and Womack (2000) explain VSM as the process of visually mapping the flow of information and material as they are and preparing a future state map with better methods and performance. According to Russell and Taylor (1999), VSM is an excellent tool for any enterprise that wants to become lean. Rother and Shook (1999) defined VSM as a pencil and paper visualization and improvement tool that shows the flow of material and information highlighting process and communication inefficiencies as a product makes its way through the value stream. As Singh and Sharma (2009) also explain, VSM allows organizations to continuously improve towards lean manufacturing by linking people, tools, processes and reporting requirements to achieve goals. "It provides clear and concise communication between management and shop floor teams about lean expectations, along with actual material and information flow". Womack et al. (1990) illustrate that value stream mapping is primarily a communication and a strategic planning tool. They highlight that the VSM method helps enterprises in understanding streamline work processes by using techniques to decrease the wastes in the process. Finally, Prabhu et al. (2008) explain that VSM derives from the lean ideology and "captures and presents the whole process from end to end in a method that is easy to understand by those working the process".

5.6.2 Visual Stream Mapping: A Tool to Identify Waste

As described by some of the definitions presented in the previous paragraph, the philosophy underlying the use of the value stream mapping technique is to help practitioners to identify waste in individual value streams and, therefore, to find an appropriate way to remove, or at least reduce, this waste. Seth et al. (2008) explain that the use of such waste removal to drive competitive advantage inside organizations was pioneered by Toyota's chief engineers and is oriented fundamentally to productivity rather than to quality. "The reason for this is that improved productivity leads to leaner operations which help to expose further waste and quality problems in the system. Thus the systematic attack on waste is also a systematic assault on the factors underlying poor quality and fundamental management problems".

As Ishiwata (1991), Monden (1993) and Murman et al. (2002) illustrate, in a manufacturing context, there are 3 types of operation that are undertaken, which can be categorized into:

- "non-value adding activities", which represent pure waste and involve unnecessary actions which should be eliminated completely, e.g. waiting time, stacking intermediate products and double handling, etc...
- "necessary but non-value adding activities", which may be wasteful but are necessary under the current operating procedures, e.g. walking long distances to pick up parts, unpacking deliveries, transferring a tool from one hand to another, etc.... In order to eliminate these types of activities, it would be necessary to make major changes to the system such as, for instance, creating a new factory floor layout.
- "value-adding activities", which involve the processing of raw materials or semi-finished products through the use of manual labour which involves activities such as, for example, sub-assembly of parts, forging raw materials and painting body work.

The value stream mapping method involves the identification of the value adding and wasteful activities mentioned above. In a manufacturing environment, wasteful operations, as Monden (1993) explains, are based on seven commonly accepted types of waste, as identified in the Toyota Production System (TPS):

1 – overproduction,
2 – waiting,
3 – transportation,
4 - inappropriate processing,
5 - unnecessary inventory,
6 - unnecessary motions, and
7 - defects.

- "Overproduction" is one of the most dangerous types of waste since it discourages a streamlined flow of products and can reduce quality and productivity. It also tends to increase lead times and storage times. As a consequence, defects may not be detected early, products may deteriorate and pressures on work rate may be generated. Also, overproduction can lead to high levels of work-in-progress stocks which result in the physical dislocation of operations and poor communication.
- The waste of "waiting" occurs when time is being used ineffectively. This kind of waste occurs whenever goods are not moving or being worked on and it affects both goods and operators, each spending time waiting. The ideal situation occurs when there is no waiting time with a subsequent faster flow of products. Waiting time for workers could be used, for example, for training or maintenance and should not result in overproduction.

- The third waste, “transport”, involves products being moved about. In theory, any movement on the factory floor could be seen as waste and so transport minimization is pursued. Furthermore, double handling and excessive movements can cause damage and deterioration due to the distance of communication between processes proportional to the time it takes to feed back reports of poor quality and to take corrective action.
- “Inappropriate processing” occurs when complex solutions are found to simple procedures. For example, the complexity can discourage ownership and encourage the workers to overproduce to recover a large investment in a complex machine. This approach can lead to poor layout and, consequently, to excessive transport and poor communication. An ideal situation is characterized by the smallest possible machine, capable of producing the required quality, located next to preceding and subsequent operations. Inappropriate processing occurs also when machines are used without sufficient safeguards with high risks of poor quality items being produced.
- “Unnecessary inventory” can increase lead time, preventing rapid identification of problems and increasing the need of space, thereby discouraging communication. Issues, which are hidden by inventory, need to be identified before being corrected. This can be achieved quickly only by reducing inventory. Also, unnecessary inventories create significant storage costs and, therefore, lower the competitiveness of the organization.
- “Unnecessary movements” involve the ergonomics of production where the workers have to stretch, bend and pick up when these actions could be avoided. Such waste is likely to decrease productivity and increase the quantity of quality problems.
- The final waste is represented by “defects” which are direct costs, and, according to the Toyota philosophy, should be regarded as opportunities to improve.

An iterative analysis of the seven wastes should lead to continuous small and incremental – rather than large and radical - system improvements.

5.6.3 Value Stream Mapping Process and Benefits

The value stream mapping tool, as Lasa et al. (2008) highlight, encompasses five main phases:

1 - selection of product family;

2 - current state mapping;

3 - future state mapping;

4 - defining a working plan;

5 - achieving the working plan.

It should be noted that, during the VSM task carried out at the company, it was not used the entire value stream mapping technique. The only relevant sections carried out at JRG Group were the “selection of product family” and the “current state mapping” since the following stages “future state mapping” and “defining a working plan” and “achieving the working plan” were identified through the computer simulation task. The five main phases highlighted above can be reworded as follows to reflect the study conducted by Hines and Rich (1997):

- the study of the flow of processes;
- the identification of waste;
- a consideration of whether the process can be rearranged in a more efficient sequence;
- a consideration of a better flow pattern, involving different flow layout or transport routing;
- a consideration of whether everything that is being done at each stage is really necessary and what would happen if superfluous tasks were removed.

Furthermore, Hines and Rich (1997) describe the practical steps involved in process mapping activity: “first, a preliminary analysis of the process is undertaken, followed by the detailed recording of all the items required in each process. The result of this is a map of the process under consideration. Each step has been categorized in terms of a variety of activity types (e.g. operation, transport, inspection, storage, etc…). The machine or area used for each of these activities is recorded, together with the distance moved, time taken and number of people involved. A simple flow chart of the types of activity being undertaken at any one time is then made. Next the total distance moved, the time taken and the people involved is calculated and recorded”. The completed diagram is then used as the basis for further analysis and subsequent improvement. Often this is achieved by asking questions such as “Why does an activity occur?” “Who does it?”, “On which machine?”, “Where?”, “When?” and “How?”. “The basis of this approach is therefore to try to eliminate activities that are unnecessary, simplify others, combine yet others and seek sequence changes that will reduce waste. Various contingent improvement approaches can be mapped similarly before the best approach is selected for implementation”.

Also Singh and Sharma (2009) in their research describe their views on the main empirical activities carried out when performing VSM tasks:

- various process symbols are drawn representing customer, supplier and production control;
- all pertinent data related to existing stages of manufacturing such as lead time, process time, change over time and no. of shifts are shown by data boxes below the VSM symbols;
- the monthly/daily requirements in terms of product, containers and kanbans are obtained;
- movement of product is shown with arrows including shipment and receiving data;
- in between two workstations WIP is shown with proper inventory icons;
- major gap areas are identified from the current state map;
- various gap areas are bridged in order to prepare proposed map;
- future state map is prepared and improvements achieved are highlighted.

“The process usually starts with customer delivery and work its way back through the entire process documenting the process graphically and collecting data along the way”, as Singh and Sharma (2009) clarify. The final outcome, a single page map called ‘”value stream’’, contains data related to cycle time, work-in-process levels, quality levels, and equipment performance. Moreover, depending on the complexity of the process and the number of components involved, additional data required may be collected from other sources. Seth and Gupta (2005) also add that the mapping activity always needs to be carried out taking into consideration the lean manufacturing principles which are the backbone of the VSM approach:

- define value from the client's perspective;
- identify the value stream;
- eliminate the seven deadly wastes;
- make the work flow;
- pull the work rather than push it;
- pursue to perfection level.

As Prabhu et al. (2008) explain, the VSM method "encourages a team approach and captures the performance measurement data to constructively critique the activity. Participants in the activity are encouraged to suggest improvements and contribute towards the implementation of an action plan". A fundamental part of the VSM process is represented by the documentation of the relationships between the manufacturing processes and the controls used to manage these processes, such as production scheduling and production information. According to Singh and Sharma (2009), this is what makes the VSM tool different from most process mapping techniques which often only document the basic product flow. VSM, in fact, also documents the flow of information within the system, and key pieces of information are represented by the locations of the raw materials and the work-in-progress and what triggers the movement of material from one process to another. Seth et al. (2008) add that the major strength of the VSM approach is to highlight individual wastes while maintaining overall perspective of the chain. They also explain that "VSM serves as a starting point to help management, engineers, suppliers, and customers recognize waste and its sources". They reckon that these concepts are developed "to understand the interdependence of one function, department or even whole unit over other and to capture holistic view about a situation where the conventional industrial engineering recording tools do not help much". Value stream mapping represents a method or tool which can hold all the data required to interpret and model an existing factory layout. As shown in Figure 5.1, the creation of a visual current state map needs to be developed with all management involved to ensure that the results are accurate and to provide a realistic and reliable "picture" of the factory floor (Lasa et al., 2008). Lasa et al. (2008) describe how this image can be used to develop a quick understanding of the production processes as all the relevant data is located in an easy to explain manner. As it can be observed in figure 5.1, it shows cycle times, shift patterns, number of operators, waiting times, number of machines at each operation, supplier delivery information, and inventory waiting times. The chart should be coupled with employee consultation to evaluate the accuracy of the timings and other data regarding each work station. The value stream mapping represents an invaluable tool for creating a basic simulated model. It should also be noted that value stream mapping is a “static picture” of the factory floor and, therefore, it is only a representation of one particular product mix. As the product mix changes, the value stream mapping may change. For this reason, it requires to be continually updated and, if needed, modified in order to always reflect the existing facility and manufacturing process design. Sometimes, due to the high variation in products, several assumptions need to be made about cycle times, waiting times and other generalizations for product families. In such cases, the use of value stream mapping for the creation of a simulated model may have to be restricted to only forming basic properties of the mock-up factory floor. A high level of attention is required when dealing with these kinds of assumptions since they can possibly affect the overall accuracy and reliability of the results of the final mapping. Finally, the value stream mapping gives a quick appreciation of how the production system operates and can be used as a validating and verifying tool for the computer simulation model - e.g. if the results of the simulation do not match the value stream mapping results, then there may be defects in the simulation model created, which will need to be amended accordingly. Hines and Rich (1997a) explain that at the end of the 90’s the results of this new type of benchmarking had been already disseminated academically and had also already been enjoyed by more than 100 UK companies that had adopted the VSM approach. This large group of organizations in same cases has applied the VSM tool also to other key processes such as sales acquisition, new product development or new product introduction. In each case the company involved had developed the framework for a change programme and was seeking to make a series of radical or incremental breakthroughs as part of this specific process benchmarking approach.

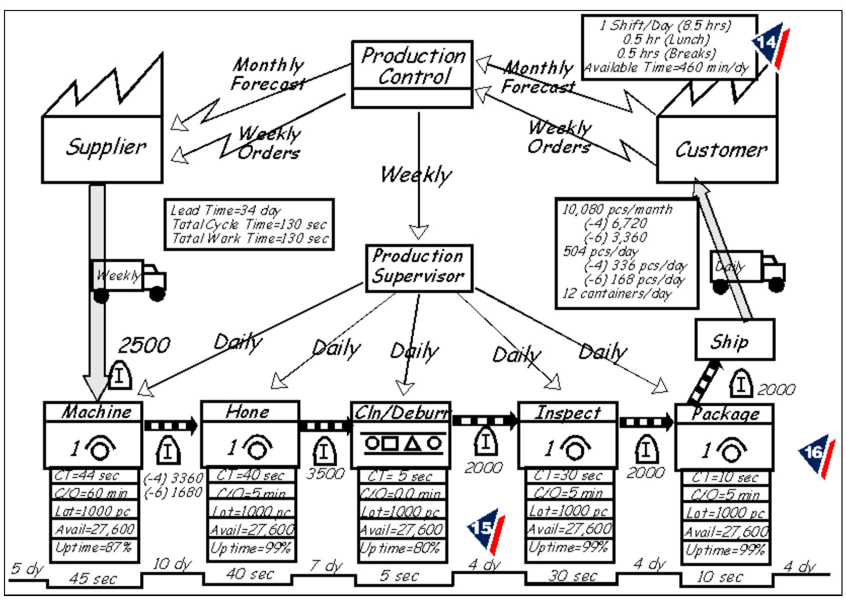

Figure 5.1 - Example of a value stream map

(Source: http://www.strategosinc.com/present_vsm.htm, March 2008)

5.7 Computer Simulation of the Manufacturing Processes

Performing experiments on real systems is highly impractical due to the negative effects that may occur. In fact, if a company is already operating at high machinery and workforce utilisation, halting production for experiments on the real processes can result in longer manufacturing lead times for customers. Moreover, another key reason for carrying out simulation modelling is represented by the fact that major changes in the production systems can also lead to further unanticipated changes. Computer simulation allows the proposition of future changes, such as new machinery introduction and elimination of predicted negative effects on the manufacturing processes. As Carrie (1988) highlights, "uncertainty is removed and replaced with certainty about expected operations of a new system or about the effects of the changes to an existing system". This is one of the many advantages of computer simulation over traditional methods of mathematical modeling or flowcharts. The use of simulation is best explained by Thomson (1995): "It is not wise or possible to modify employment rate, positioning of machinery, and change in procedures or incorporate new management philosophies without consideration of implications". In manufacturing, these implications are best identified and analysed through simulation. As Lehaney (1993) states, simulation is "particularly useful for 'What-If?' experiments, which could not be carried out in the real system".

Computer simulation has a wide range of applications in many different fields. Over recent years, computer simulation has become an invaluable tool in the manufacturing industry. Simulation allows companies to analyse and predict future behaviour without spending time and money to experience the real effects. In fact, a computer replicates the exact environment of the shop floor facility and provides an overview of changes in behaviour and requirements, based on the input information and simulated conditions. As Robinson (1993) states, this has become "a powerful tool in decision making" since it allows forecasts of changes to be made based on solid evidence, with very little cost to the organisation. There are many different situations where computer simulation can be applied to, all with varying degrees of complexity. According to Carrie (1988), within a manufacturing context simulation is the mimicking of real life which allows company processes to be observed and analysed while they are "in-progress", resulting in performance measurement and effect of changes made in the system under investigation. When updating existing systems, indentifying problems, recording results and designing new facilities, simulation represents an essential tool in understanding all the factors in specific manufacturing situations. In current manufacturing, simulation is required since there is no company-wide understanding of the processes, mainly due to complexity of the production – e.g. variable routings, no standard orders, etc...

Carrie (1988) explain that there are several steps involved in a simulation project:

- Define the system to be modeled;

- Build the model;
- Collect the data;
- Verify and validate the model;
- Run experiments using the model;
- Revise the model and repeat the experiments.

In the simulation process, the validation and verification stages are fundamental steps required to allow the model to be checked in order to ensure it accurately represents the real manufacturing processes in place in the factory floor. According to Greasley (2004), the verification stage of the model makes sure that the model is a “correct representation of the system” while the validation phase is “to ensure that the model’s behaviour is close enough to the real-world system”. As Fielden (2001) explains, the verification and validation are necessary steps since the systems cannot “’ratify’ data on its own, but it can ‘confirm’ decisions made by the operator”.

There are several ways to verify a model, each of which is incremental in analysing and checking the input data. One method of verifying the model is to use a technique that reduces the complexity of the model. Often, as a model gets bigger, it becomes more and more complex, which can be much more difficult to check upon completion. To avoid this problem, the model can be built one stage at a time and checked after each stage is completed. This aims to “eliminate the search for errors” (Greasley, 2004).

Another method of verification is represented by a structured walkthrough, which involves talking someone who was not involved in building the model through the manufacturing process the model tries to depict. This approach forces the creator to think and explain what was done and why, and also gives a fresh insight from someone who needs to understand clearly the process from the explanation of the creator. Using test runs can also verify a model, as it can analyse the model against predicted behaviour. Multiple runs require be carried out to identify obvious faults in the system, which can be highlighted through experience or historical data. Finally, a trace analysis allows the operator of the simulation model to track an entity through the real complete system. The data recovered from this trace can then be matched against the information predicted by the simulation run, which can then determine how accurate the model is.

Once the verification of the model is complete, then the model needs to be validated which can be done in several different ways. Validation aims to check that the model behaves as intended and, when “working”, it represents the real environment it is trying to reflect. Conceptual validity can be tested ensuring that the elements within the model give an accurate representation of how they work in the “real world”. The main focus of the checks is to make sure that functions such as shift patterns and machine process times depict the “real ones”. Much of the validation process can be done checking data and having production managers look at the system to ensure it reflects their own experience. Operational validity is to validate that a model is performing exactly like the real system. To this purpose, the model is set up and run with various problem points and times before they actually occur on the factory floor. The operators can then check if these issues occur around the same time as predicted by the software, showing its validity and reliability against the real environment. Finally, the model must be validated through believability, which requires close communication between both creator and client. The client must understand the model and how it operates in order to believe the results generated from it. Only if the results are believed, the customer is keen to follow the recommendations developed through the analysis of the simulation run outcomes to improve the current situation.

It is clear that the manufacturing system needs to be fully understood in order to be replicated. The steps highlighted above allow to create and utilize the correct model which presents the best representation of the real life conditions in the factory. However, sometimes, due to time restrictions and software knowledge, the ability to accurately replicate the exact conditions of the manufacturing facility is reduced, and consequently the final model provides only an approximation of the manufacturing processes in place within the organization. Creating a simulation that is 100% accurate is, as a result, very difficult due to the complexity and the specificity of the production environments, and very often many assumptions need to be made and only a basic model is created to give a general representation of the problems likely to be experienced on the shop floor. When it is the first time that the shop floor of an organization is modelled and the production processes simulated, many assumptions are made and the process itself acts as a general base for any future simulations. However, even if the simulation has a number of assumptions, it educates people about the system since very often the manufacturing process in place within organizations is complex and there is little understanding of the process interactions and how they impact on the overall business performance.

When previous analyses of the production environment have never been carried out, computer simulation provides an insight into critical areas within the shop floor and allow personnel to view and monitor the possible effects of changes, such as, for instance, improved product delivery time estimations to customers. Very often the workforce is resistant or apprehensive of major changes. The simulation of planned changes, for example in manufacturing capabilities or floor lay-out, can act as a means of communicating the change along with the reasons and the effects. As Greasley (2004) explains, "individuals can predict the effects of change, thus allowing them to accept and understand change and improve confidence towards the implementation". Simulation, therefore, allows the workers to justify the planned changes to understand the reasoning for change as it gives reason for the alteration with the expected results. As Lehaney (1993) remarks, computer simulation uses a mathematical approach which "broadly speaking, may be discrete event or dynamic". As opposed to static models - which allow random processes in a business to be modelled, but can only work within pre-set guidelines and need the data to be entered before commencing the simulation - the dynamic approach to modelling can focus on either continuous or discrete event simulation, both of which change over a period of time and have indeterminable results. A continuous model is constantly changing in direct proportion to the length of time the model is active. A discrete event simulation has less change, which only occurs at discrete events during the simulation. For the simulation of the manufacturing processes at the company, it was best to use discrete event simulation since the processes involved in production could be represented by events which changed in a discrete way. This type of simulation focuses on the events which consume no time in the system, such as arrival at queue, beginning and end of a process. Within discrete event simulation, there are three distinct techniques: activity based, event based, and process based. The computer simulation software utilised to perform the simulation task in this research study - a visual tool known as Visual Interactive Modelling (VIM) system since it shows graphically the changes made to a system - uses a process based package which suited the manufacturing system modelled at the company. This type of package allows work items to flow through the system with their route determined by the attributes assigned upon entering the system. These attributes indicate to each work item which path they are to follow through the system. Computer simulation is used to model factory operations and specific software packages are used for developing relevant models. “Simul8®” was the simulation software package selected for creating a manufacturing process model for this research study at JRG Group for a number of reasons, as it will be described in chapter 6. According to Goyal et al. (1995), the main advantages achieved by companies when using computer simulation to predict a manufacturing scenario were:

- reduction of the risk of installing a new system;
- representation of important characteristics of the system (integration of more complex interactions which may only exist between various variables);
- easy visual evaluation of the current situation and future predicted scenario in a controlled environment;
- ability to calculate directly the measures of performance which helps to address the same measures for hypothetical production process configurations set up to evaluate real systems.

The use of simulation is summed up by O’Kane at al. (2007) who explain that “simulation can provide a unique insight into production issues, which identify opportunities for system improvements. In particular, production improvement in terms of production planning, scheduling, layout planning and optimization of processes are key areas in which simulation can support operational decision making”. Simulation allows a company to analyse a wide range of manufacturing possibilities available for improvements, without the need to change anything within the production process until some simulation runs have been carried out and the results generated have been evaluated. Some of the areas that simulation can address are, as O’Kane et al. (2007) again explain, “bottlenecks that result in high work-in-progress inventory level and low resource and machine utilisation. Simulation can evaluate machine performance, cycle times and production data, the levels of faults and assess various scheduling rules, which are essential to efficient production control". Or, as Greasley (2004) states, "simulation provides a way of experimenting with a model of an organizational system in order to understand its behaviour under a number of scenarios". In a situation where a manufacturing system can be improved and the actual situation requires to be analysed in order to design a new scenario, simulation provides the perfect tool to explore the possible ways of improvement. The effect of each simulated scenario can then be evaluated in theory, enabling the organization to maximise the increase in performance while minimizing any unwanted side effects before applying the adjustments identified into the "real-life" context.

5.8 Quality Function Deployment (QFD) Study

5.8.1 Definitions and Literature Review

A review of the reasons why companies understood the need to establish and use a QFD-type of approach in order to succeed in meeting their customer satisfaction has been carried out and it is described in the following.

According to Damon and Schramm (1972), global competition has forced many companies to compete in many dimensions including cost, customer service, time and quality, in order to ultimately achieve customer expectations. Some authors reckon that the continuous changes that affect the business environment, due to the globalization process and the technology innovations, force organizations to constantly look for new competitive advantages in order to maintain and improve their market position. It is clear that contemporary economic conditions dictate the involvement of all units in the company in the cause for quality improvement. Dube et al. (1994) state that the lack of management in customer satisfaction strategies could be one of many factors leading to a company's collapse. To effectively draft customer satisfaction strategies, one must respect customer value, gather customer demand data and then compare the importance and performance between the collected customer demand information (Naumann et al., 2001). Concurrently, customer demands are not stagnant and cannot be manipulated by organizations. Therefore, companies must periodically diagnose and filter these demands to set reasonable strategies to ensure the survival of the customer satisfaction activities (Chien and Sue, 2003). Knox (1998) used product/service content and the ability to satisfy customer demands as the basis for customer satisfaction strategy analysis. According to several authors, in order to analyze customer satisfaction strategies, three factors need to be considered: expectation and past experiences, product and service performance, and the factors affecting actual perception. They subsequently concluded that the customer satisfaction should be the summation of each customer demand, satisfaction level and importance factor. Hauser and Shugan (1983) state that there are four departments which are essential in achieving customer satisfaction because they are directly involved in product and service development: marketing, sales, design and manufacturing. Furthermore, as the researchers note, these areas must be linked in order to develop products and services focused on the customer. The product/service development process starts with the customer (acquiring information) and ends with the customer (delivering product/service and obtaining feedback). This process should be ideally developed and carried out by a cross-functional team, which should involve people from different departments within the organization (Gonzales, 2001). Also, the organization must continually seek customer feedback on wants and needs and must also find out areas of new needs or requirements through a systematic gathering of intelligence. Marketing and sales, therefore, must gather reliable and timely information from the customer and share it with the rest of the organization (Jaworsky and Kohli, 1993). In turn, design must use this intelligence to design products and/or services that meet and exceed customer requirements. Design, however, must also consider manufacturability aspects, so that the new design is feasible for production (Kummar and Sudarshan, 1988). Gonzales et al. (2004) highlight that several studies have showed that product quality is directly enhanced through the development of close relationships between manufacturing and marketing/sales functions with regard to both product development and process development decisions. Wheelwright and Clark (1992) demonstrated that a close relationship between manufacturing and marketing/sales not only leads to improved product designs, but also to increased efficiency in the production of those products, both of which lead to increased organizational performance. Skinner (1986) argues that attaining a competitive advantage requires a link between the marketing and the manufacturing strategies, and both should be a fundamental part of the corporate strategy. Indeed, when companies fail to recognize the relationship between manufacturing strategy and corporate strategy, they may become saddled with non-competitive production systems that are expensive and ineffective. While some organizations have attempted to build competitive advantage by focusing on efficiency and productivity, these efforts usually lead to only modest improvements and are not sufficient in a post-industrial environment. According to Lu and Kuei (1995), total quality control stresses the long-term planning aspect, and it has traditionally focused on the technical aspect of providing a quality product or service. Marketing and sales, however, often provide market and customer information that is short-term and is therefore of limited use to manufacturing (Griffin and Hauser, 1992). What is lacking in the current process to satisfy customers is a strategic approach that could be applied across all functional departments in a totally integrated environment. Several researchers state that organizations must develop integrated strategies that link various departments in order to respond as a single, stronger unit to market uncertainties - rather than small, weak and independent entities working for their own benefits. More characteristic, however, is an organization where every department tries to achieve its own objectives and goals. Gonzales et al. (2004) argue again that this issue is often overlooked and might interfere in the achievements of the company's overall objectives. Further, it might have a negative impact on customer satisfaction, as the voice of the customer is not always communicated effectively to engineering and manufacturing. Gonzales et al. (2004) see Quality Function Deployment as a tool for linking all functional departments and especially marketing and manufacturing strategies. They state that the important relationship between marketing and manufacturing has been recognized since the late 1960s when the Japanese developed quality function development as a way to translate the voice of the customer into design specifications. However, they argue that, according to researchers and managers, there is still a lack of agreement between marketing and manufacturing managers on critical strategic issues. They also states that by developing and implementing a system that focuses on customer expectations and product specification, the company becomes more competitive.

5.8.2 History of Quality Function Deployment

Quality Function Deployment (QFD) is a concept that originated in Japan at the end of 1960s as a concept for new product development linked to Total Quality Management. At that time Japanese industries were thinking of changing from product development based on imitation and copying to product development based on originality. After the Second World War, in Japan a new theory was developed and introduced in business management - and especially in the automobile industry – which emphasized the importance of involving the entire workforce in its implementation. This concept originated as statistical quality control (SQC), which then became total quality control (TQC) and , eventually, total quality management (TQM). It was when all these changes were happening that Akao presented the concept and method of QFD. He focused on two main issues which helped him to conceive the idea of QFD. First he realised that people were starting to notice the influence that design had on quality. However, at that time there was no information on how it could be done. He also realised that quality control process charts were being used by companies but these charts were elaborated after the new products were finished. Early in the 1970's Akao in his publication "New Product Development and Quality Assurance – Quality Deployment System," put together this concept and his experiences. The term "*hinshitsu tenkai*" (quality deployment) was described here for the first time. Although the concept was useful it was still inadequate in terms of setting the design quality. This concept was improved some years later by the Kobe Shipyards of Mitsubishi Heavy Industry which created the quality chart. All these ideas and developments were integrated and eventually shaped into Quality Deployment (QD). Another idea from "value engineering" influenced QFD. Value engineering demonstrated a way to define the functions of a product. This concept was then expanded to business process functions. This set the bases for what later was narrowly defined as Quality Function deployment (QFD).

QFD has evolved over the years. Nowadays QFD contains a lot of new ideas and concepts that were not in the original QFD theory. Some companies have found that the approach of traditional QFD does not integrate well into their new product development process since it consumes too much time. Also, in traditional QFD the voice of the customer was not given the importance that it deserved, therefore it was difficult for companies to discover the unspoken needs. Modern QFD is more customer-orientated and it seeks to utilize the appropriate tools and sequence in order to identify the minimum effort required. This makes QFD more efficient. Large and complex tools such as the "house of quality" (HOQ) in many cases have been replaced for smaller and faster tools making their analysis easier and faster. Maths has also been integrated in the QFD matrices which make them much more accurate. One of the priorities of modern QFD is to refine the voice of the customer in order to discover the spoken and unspoken customer needs. Modern QFD also includes psychological and lifestyle needs, not just functional needs. Components for schedule deployment and project deployment are also part of the modern QFD.

"Quality Function Deployment (QFD) is a system for translating consumer requirements into appropriate company requirements at each stage from research and product development to engineering and manufacturing to marketing/sales and distribution" (American Supplier Institute, 1989). QFD is one of the most successful tools to integrate customers, design, and production. It is a fact that the success of a company also depends on how well they understand and are connected to their customers. "Tomorrow's most successful companies must understand clients' needs better than the clients do" (QFD institute). QFD nowadays is evolving towards a methodology based on strategic product planning which helps new product development to make the products more attractive to the customer. Therefore, it is important that new methods are developed to achieve a close relationship between QFD and marketing. TQM is a fundamental method to align company-wide activities to customer focus. It is important for companies to ensure that all the employees focus on customer satisfaction and QFD is the means to accomplish this task. Cohen (1995) states that a QFD process includes four phases: product planning ("house of quality"), product design, process planning, and process control planning. One of the basic elements of the QFD process is the "house of quality" matrix, which consists of six "rooms":

1. Whats (consumer requirements)
2. Hows (technical descriptors)
3. Relationship matrix
4. Correlation matrix
5. Prioritized customer requirements
6. Prioritized technical descriptors

5.8.3 Benefits from Applying Quality Function Deployment

Various applications and studies have shown many benefits of QFD. Sullivan (1986) stated that QFD brings efficiency to companies because misinterpretation and need for changes are minimized. Bossert (1991) give details of QFD's benefits such as more customer orientation, reduction of implementation time, better promotion of teamwork, and higher customer satisfaction which leads to customer loyalty that results in future businesses. Brown (1991) concludes that QFD leads to superior product quality and design, shorter design cycles with fewer engineering changes, higher potential for radical innovations, lower product and project costs, and more satisfied customers. Burrows (1991) emphasizes the strategic benefits such as better understanding of customer needs, increased quality of advertising and communication, and faster decision making. Vonderembse (1997) states that QFD offers product development teams the opportunity to achieve significant improvements over traditional product development practices. QFD creates an information intensive environment where communication increases and ideas are freely exchanged. This has a positive impact on developing product concepts and devising designs that meet customer quality and performance objectives. According to his studies, QFD results in better communication and documentation efforts which may lead to enhanced organizational learning, and higher levels of customer satisfaction. He states that QFD may also enable the firm to cut product costs and reduce time-to-market. He also assures that the results of his researches show that QFD is able to simplify the manufacturing process, but overall product costs appear to be only slightly less when QFD is applied than when traditional practices are used. The reason for this small improvement in product costs and time-to-market may be a lack of experience with QFD. As companies gain experience with QFD and learn to apply it more effectively, product costs and time-to-market may decline. It is important to notice that studies have found that QFD should be implemented in the very early phases of the product development cycle to make sure that all major design conflicts and problems are solved before prototyping and before production is started.

5.8.4 Issues and Barriers Associated with Quality Function Deployment

Bouchereau and Rowlands (1999) explain that the following issues can be associated with QFD:

- the possible ambiguity in the voice of the customer;
- the need to analyze large amounts of subjective data;
- the manual input of client survey data into the house of quality is time consuming and difficult;
- the house of quality can become large and complex;
- setting target values in the house of quality can be inaccurate;
- the strengths between relationships are sometimes vague;

- the QFD studies sometimes can be only qualitative.

Sometimes, there are also some challenges and barriers that companies should overcome when applying QFD. According to Shillito (1995), the most frequent challenges are:

- Lack of management support*:* Although managers are the first ones who should be committed, in practice this does not always happen. When the working teams are formed, they are given an amount of time to work on the project. Very often these teams are also working on other projects or activities. Teams will give more priority to the QFD project only if it is considered more important for management. This will cause lack of commitment and discontinuity on the project.

- Lack of time: Most of the time team members are under pressure trying to meet schedules on different projects and see QFD as a delay to achieve this goal. It is not easy for team members to see the benefits of QFD at the beginning of the project and they will not risk meeting the schedule by getting involved in a process which they are not sure will work.

- Change*:* There is always a fear of change and people resist changes, especially product designers, manufacturing managers, production engineers, assembly people and plant management. This a great challenge when applying QFD as it seeks to change the product process and might cause changes in all these areas.

- “We are already doing it”: In some companies some ideas of QFD could be familiar for teams. Perhaps they have or are already using some QFD-type data. But usually these data are isolated and not connected through any structure. Since QFD data sometimes look familiar, people believe they are applying QFD. It can be difficult to convince individuals to use the proper QFD process to structure and quantify the relevant information.

5.9 Process Failure Mode and Effect Analysis (FMEA) Study

5.9.1 Brief History of FMEA

One of the similarities amongst various existing theories and models on total quality management (TQM) is the emphasis upon continuous quality improvement through failure identification and adjustment. Before the evolution of TQM principles, the scope of the term “failure” was restricted only to “product failures”. However, as Devadasan et al. (2003) explains, “the TQM principles’ view of failures refers to those caused in products, processes, services and throughout the system”. One of the methods developed to accomplish continuous quality improvement deals with failure identification and rectification and it is known as “Failure Mode and Effects Analysis” (FMEA). FMEA was initially developed as a design methodology in the 1960s by the American aerospace industry (NASA) in order to comply with specific and strict reliability and safety requirements. Since then, it has come to be applied extensively in order to ensure the safety and reliability of products in a wide range of sectors, particularly the aerospace, automotive and nuclear industries (Sankar and Prabhu, 2001).

5.9.2 Aims of FMEA Studies

Customers are placing increased demands on companies for high quality and reliable products which is more difficult to maintain due to the increasing capabilities and functionality of many products. Traditionally, reliability has been achieved through extensive testing and use of methodologies such as probabilistic modelling. These are techniques performed in the late stages of the product development. The challenge nowadays is to design in quality and reliability early in the development cycle. Failure Modes and Effects Analysis is the methodology for analyzing potential reliability problems early in the development cycle where it is easier to take actions to overcome these issues, thereby enhancing reliability through design. The early and consistent use of FMEA in the design process allows engineers to avoid failures and produce reliable, safe, and customer pleasing products and processes. Therefore, the main aim the FMEA technique pursues is represented by the identification of the potential failures which may occur in the design and manufacture of products and the investigation of their possible sources. It also aims to ensure that resources are available when necessary, to establish preventive and corrective action so that failures do not occur or re-occur, and, finally, to re-assess the effectiveness of the corrective actions identified and carried out to prevent the failures from re-occurring.

The following are the main purposes of FMEA studies performed by organizations:

- develop product or process requirements that minimize the likelihood of those failures;
- evaluate the requirements obtained from the customer or other participants in the design process to ensure that those requirements do not introduce potential failures;
- identify design characteristics that contribute to failures and design them out of the system or at least minimize the resulting effects;
- develop methods and procedures to develop and test the product/process to ensure that the failures have been successfully eliminated;
- track and manage potential risks in the design;
- ensure that any failures that could occur will not injure or seriously impact the customer of the product/process.

In the following, several definitions and scopes of this methodology are reported based on what was retrieved from the relevant literature on the subject in order to highlight the various perspectives of the different authors.

The FMEA Info Centre (2009) describes that the methodology is “an easy to use and yet powerful pro-active engineering quality method that helps to identify and counter weak points in the early conception phase of products and processes. According to Chrysler Corporation et al. (1995), FMEA can be described as a systemized group of activities intended to recognize and to evaluate the potential failures of a product/process and their effects. Teng and Ho (1996) highlight that in production processes, even at the early design stages, high levels of reliability need to be achieved and costly corrective action at later production stages need to be avoided. The FMEA allows to take into consideration both the clients' reliability criteria and potential flaws in the operations of the process. Dale and Best (1988) consider FMEA as a problem prevention tool and Clifton (1990) explains that the FMEA method is based on systematic brainstorming aimed at revealing the failures that might occur in a system or process. Teng et al. (2006) point out that organizations implement design and process FMEA to improve the reliability and quality of their products, to correct potential problems, and, often, to satisfy specific industry standards and requirements. They highlight that "performing FMEA requires teamwork, management support, product and process knowledge, sufficient time for thorough discussion, and money. So utilizing FMEA results fully in design and production is critical to make the entire system cost effective and to gain the most benefits from the investment in the FMEA activities." Furthermore, Teng and Ho (1996) again explain that "FMEA provides basic information to reliability prediction, and product and process design. FMEA helps engineers find potential problems in the product earlier and thus avoids costly changes or reworks at later stages, such as at the manufacturing stage and at the product warranty stage." They carry on highlighting that "the FMEA analysis process provides a thorough analysis at each detailed functional design element. It allows FMEA to be a very useful tool in quality planning and reliability prediction." McDermott et al. (1996) state that the FMEA method also educate the personnel to team work in order for the workforce to identify the defects and the causes leading to them, propose preventive action, and evaluate the results. Ireson et al. (1995) argue that FMEA establishes an effective risk management environment since it represents the potential product/process failures and the planned responses to these failures. They also clarify that it "helps users to identify the key design or process characteristics that require special controls for manufacturing, and to highlight areas for improvement in characteristic control or performance." Again, Chang and Sung (2009) explain that the FMEA method allows engineers to show in a structured and formalized way subjective thinking and experiences by identifying and prioritizing corrective actions to eliminate or reduce failure rate, thus enhancing product/system performance. Vandenbrande (1998) writes that FMEA "is a group-oriented, structured, and stepwise approach to quantify the effects of possible failures, thus allowing a company to set priorities for action." Ginn et al. (1998) reckon that the FMEA is more than just a technical tool, but is in practice a communication tool that "acts as the catalysts to spark off teamwork and in doing so enables a company-wide cross-functional, multidisciplinary network of teams that share like minded goals that in turn foster a broader total quality management culture". Tay and Lim (2006) believe that "FMEA is an effective problem prevention methodology that can easily interface with many engineering and reliability methods". Webber (1990) reckons that FMEA techniques ensure total customer satisfaction and also save lost production capacity. Shahin (2004) in his definition focuses more on the customer side and explains that FMEA is typically used as a problem prevention means to improve the client needs in order to avoid negative customer satisfaction before the failure takes place. Finally, Ginn et al. (1998), when trying to define QFD and FMEA, highlight differences and similarities between these two types of studies. In particular, they point out that "QFD is the guardian of the voice of the customer, while FMEA is the guardian of the voice of the engineer. These two quality tools are tackling the same issue of customer satisfaction, but from different perspectives of positive and negative qualities which need to be taken into account equally". To this regard, Clausing (1994) also describes how, within the product development cycle, an FMEA can add valuable "piece part expectation" detail to the QFD process.

5.9.3 Types of FMEA

There are various types of FMEAs:

- system: focuses on global system functions;
- design: focuses on components and subsystems;
- process: focuses on manufacturing and assembly processes;
- service: focuses on service functions;
- software: focuses on software functions.

The most common types of FMEA are represented by the design FMEA and process FMEA. As Puente et al. (2002) argue, potential issues can be analysed and possible faults can be identified before they are passed on to the customer, their effects on the overall system can be studied and the right control decisions can be made, in either of these two stages, avoiding added costs generated by later modifications during the production phase. As Teng and Ho (1996) highlight, "all engineers involved in the project should consider process/product quality and reliability…the design team must check the adequacy of the product design since the design may not meet the customer's reliability requirements. The production team should examine the possible flaws in manufacturing operations." Puente et al. (2002) clarify that "to cover both design and production, the FMEA ideally should include the activities at both design and manufacturing stages. It is common to conduct this type of analysis at the earliest stage of the product life cycle. Design and product engineers usually work with a project team that includes customers, reliability engineers and manufacturing engineers to identify the potential quality and reliability failures in the design process in order to eliminate the problems as early as possible to avoid complicated and costly correction processes". Ginn et al. (1998) explain that the FMEA is nowadays considered "as a system or concept FMEA which is supported by design FMEAs which in turn support process FMEAs". Finally, Aldridge et al. (1990) highlight that practice has proved that process FMEA is more readily incorporated into existing company quality structures since most of the benefits are more readily visible and, when the client supplier chain is illustrated as clearly as a production line, it is easy to see how failures impact on the product, customer and subsequent processes. As it will be described later on, this is also the case of the FMEA task carried out during this research study.

5.9.4 The FMEA Procedure

According to Puente et al. (2002), the FMEA consists of two phases. During the first phase, potential failure modes of a product or process and their effects are identified; this stage is related to the detailed design stage and includes the definition of possible failures in the components of the product, the sub-assembly, final assembly and the manufacturing process. During the second stage, the engineering team that developed the FMEA determines the risk score of these failures and puts them in order, reviewing each design detail and proposing the relevant modifications. “The most critical failures will head the ranking, and will therefore be considered first during design review or during corrective actions taken to minimise the likelihood of their occurring”.
More in particular, Takezawa and Takahashi (1990) classify four key FMEA procedural stages:

- identify the function of each system, component or process element;
- examine the root causes of problems and failure modes correlated to the customer, environment and interacting systems;
- analyse the effects of the problems and prioritise the causal factors;
- investigate the relationships to causes through failure analysis methods and identify appropriate counter measures.

They explain that “these stages involve identification of the perceived function by the customer, identification of customer usage patterns, prioritization of important factors and the selection of measures to explore relationships”. Sankar and Prabhu (2001) describe the FMEA method highlighting that the staff involved in the analysis makes the most of its subjective thinking and experience by answering questions such as “what might go wrong?”, “what might cause it to go wrong?”, “what effects would it have?”. They carry on explaining that, once the FMEA is completed, a critical item list is compiled “enabling the analyst to pinpoint system inherent vulnerabilities, thus ensuring that safety, quality and reliability are built into the design and manufacture stages of products”. The Society of Automotive Engineers (1993) also clarifies that, when carrying out the analysis, “the behaviour is evaluated for every potential failure mode of every system component. Where unacceptable failure effects occur, design changes are made to either eliminate the causes of failure or to mitigate their effects”. As far as the participants are concerned, the FMEA process involves gathering representatives from the various stakeholder groups, such as manufacturing, process engineering, equipment engineering, test or product engineering to collectively complete the analysis, as Raisinghani et al. (2005) explains. The process starts with a process map similar to the business process analysis. The process is systematically investigated to "proactively determine what could possibly happen detrimental to the product at each step of the process". They conclude highlighting the outcomes of the analysis by clarifying that "the FMEA process may identify areas that require a designed experiment for optimization or even require the purchase of new metrology equipment if the exposure to potential problems is too great." Teng et al. (2006) in their research study describe the features of the FMEA worksheets. They highlight that the FMEA report is a living document and is the key document for product and process design. "The participants update the FMEA report whenever a product's design is changed, a new failure mode is identified, or an error proofing design is implemented". Throughout the product development cycle change and updates are made to the product and process. These changes can and often do introduce new failure modes. It is therefore important to review and/or update the FMEA documents, especially when:

- a new product/process is being initiated (at the beginning of the cycle);
- changes are made to the conditions the product/process is expected to function in;
- a change is made to either the product or process design (the product and process are inter-related. When the product design is changed the process is impacted and vice-versa);
- new regulations are introduced;
- customer feedback highlights problems in the product or process.

Finally, Teng et al. (2006) explain that there can be several reports generated from the FMEA study which cover aspects such as the verification or test plan – once the failure modes have been recognized and the control methods identified, the critical item list – after the risk priority ratings have been identified, the action plan – once the corrective actions, based on the priorities previously identified, have been decided and agreed by the FMEA team, the lessons learned, and the design guidelines. The detailed procedure to conduct an FMEA study and its specific application during the project have been described in this dissertation later on when discussing about the tasks carried out during the research study.

5.9.5 Benefits Achieved by Companies after Applying FMEA Studies

Many are the benefits achieved by organizations after they put in place an FMEA programme within their facility, as it was found in the relevant literature review and reported in the following.

Tang and Ho (1996) explain that the main benefits accomplished by companies implementing FMEA were represented by improving the product/process quality and reliability and increasing the customers' satisfaction. Webber (1990), in his research describes that companies have "found FMEA a consistent, cost-effective and objective means of obtaining hard facts, since random quality checks would be unlikely to detect the existence of isolated defects”. Dale and Shaw (1990), in providing a list of the advantages achieved by organizations, highlight that customer specifications were better met, costs and launch times were cut since redesign and modifications were avoided and many tests eliminated, and product/process quality and reliability improved, which led to increasing the safety and responsibility during the design and manufacturing process. “In short, problem prevention rather than problem correction is focused on, and the number of customer complaints drops”. A proper use of the FMEA reports, as Teng et al. (2006) point out, provided companies with many advantages such as increase of product reliability, decrease of design modification, better quality planning, continuous improvement in product and process design, lower manufacturing cost, and, ultimately, to better fulfilling the customer needs. Finally, Ginn et al. (1998), when describing the advantages accomplished by cross-functional FMEA teams, highlight that they allowed to “step outside the organizational structure and look at new product planning and problem solving issues, perhaps more objectively than organizationally structured teams. The argument above supports the use of FMEA as driver to bring the voice of the customer and voice of the engineer closer together along the ‘performance quality line’”.

5.10 Manufacturing Process Improvement Programmes

Once completed the analysis of the literature on the specific tasks carried out during the research project, the review moved on to investigate, within the literature on production and operation management, the results of other similar integrated improvement programmes carried out within the general manufacturing industry in the past years. In the following the findings of this investigation are reported.

5.10.1 General Literature Review

A review of some books was initially carried out on the manufacturing process improvement and optimization topics.

It was found that many authors dealt with optimization principles in manufacturing engineering. In particular, Shiba et al. (1993) analyses the different aspects of applying Total Quality Management within manufacturing environments. Rhyder and Dekker (1997) present a set of manufacturing process optimization and improvement tools and techniques, such as Pareto charts, Ishikawa diagrams, statistical process control charts, design of experiment procedures, etc... In their study, they highlight the main aspects to consider when trying to optimize the quality and productivity of a manufacturing process, i.e. the operation of the process itself, the available processing equipments, the processing capacity and reliability of the machinery, the processing material used, and the available operations personnel. Moore (2006), an industry consultant, analyses the factors related to the selection of the proper manufacturing improvement tool, also focusing on aspects such as when carrying out the selection process and when applying it into practice. He outlines the essential aspects of the main quality management tool in manufacturing, such as Six Sigma, Lean Management, Kaizen Management, etc…, explaining comparative advantages and disadvantages of each of them. He finally highlights the need for the organization to align, meaning that management, marketing and business growth strategies must align in order for the manufacturing improvement techniques selected to “work” properly. Koenig (2007), finally, reviews every aspect of the manufacturing operations, focusing also on using ISO9001 to become a “world-class” company.

5.10.2 “Stand-Alone” Techniques

The literature analysis then investigated papers and articles on specific “stand-alone” methods carried out to achieve manufacturing process improvement.
Maskell (1987) describes the now well-known concept of “Just-In-Time” manufacturing covering aspects such as the steps required to establish it, customer-supplier relationships, shop-floor layout and Manufacturing Requirement Planning (MRPII) systems. Daniels (1993) explains how to bring the advantages of flow type production to batch production in order to achieve more flexible manufacturing systems that can respond more quickly to changes in demand in terms of volume and product mix offering some of the benefits of the economies of scale. Edwards et al. (1993) describe the features of standard operations arguing that they represent the key to continuous improvement in a just-in-time manufacturing system. Banker et al. (1993) examine the shop floor reporting policies on manufacturing performance of forty-two United States-based companies. They document that the extent of information concerning the status of manufacturing, such as defect rates or schedule compliance and productivity information, provided to workers on the shop floor is positively related to the implementation of continuous quality improvement programmes. Vokurka and Davis (1996) describe a quality improvement implementation case study carried out in terms of scrap reduction initiatives within a manufacturing organization. Hines and Rich (1997) describe seven value stream mapping tools – process activity mapping, supply chain response matrix, production variety funnel, quality filter mapping, demand amplification mapping, decision point analysis, and physical structure mapping - to be used to eliminate or reduce the seven main types of wastes – overproduction, waiting, transport, inappropriate processing, unnecessary inventory, unnecessary motion, and defects – in order to accomplish manufacturing performance optimization. Tranfield (1999) studies team working types and practices within an organizational and strategic context with the aim of redesigning the organization to pursue manufacturing improvements. Huang et al. (2002) describe an overall equipment effectiveness-based (OEE) approach to model the productivity of a manufacturing system in terms of overall throughput effectiveness (OTE) in order to achieve productivity improvements. Zantek et al. (2002) offer a procedure for measuring the effect of the

performance of each manufacturing stage on the output quality of subsequent stages including the final product and identifying stages in a manufacturing system where to concentrate investments in process quality improvement. Grunberg (2004) presents a definition of performance, productivity and profitability and the main relationships between the concepts and describes a method for finding and prioritizing potential performance improvement areas in manufacturing operations. Franceschini and Galetto (2004) investigate learning behaviours related to quality improvements in manufacturing systems. In particular, they study the ability of reducing defectiveness over production cycles adopting the logic of Process Quality Improvement. Sukthomya and Tannock (2005) describe the methods of manufacturing process optimization using Taguchi experimental design methods with historical process data gathered during normal production. The findings of their study prove that the method is a powerful problem solving technique for improving process performance, yield and productivity. It reduces scrap rates, rework costs and manufacturing costs due to excessive variability in processes. Raisinghani et al. (2005) provide a discussion on the “Six Sigma” methodology highlighting concepts, tools and applications, and investigates how it relates with other quality initiatives. They explain that the immediate goal of “Six Sigma” is defect reduction. Reduced defects lead to yield improvement and higher yields improve customer satisfaction. “Six Sigma” defect reduction is intended to lead to cost reduction. “Six Sigma” has a process focus and aims to highlight process improvement opportunities through systematic measurement. “Six Sigma” is a toolset, not a management system and is best used in conjunction with other more comprehensive quality standards. Finally, Lee-Mortimer (2008) examines the introduction of Kanban production control at a UK-based manufacturing organization. He explains that this “pull” system was combined with broad involvement, widespread training and the addressing of cultural issues and delivered the expected dramatic reductions in lead times and inventory.

5.10.3 General Integrated Programmes

The literature review then moved on to analyse articles and papers on integrated general programmes focused on the improvement of the manufacturing process performance of organizations operating in various markets.

Instone and Dale (1988) present a case study on the typical issues - such as determining whether or not quality improvement was necessary and how the existing quality system could have been developed - involved in a quality improvement programme carried out at a manufacturing organization. Draajjer (1992) investigates in ten case studies the level of market orientation of manufacturing improvement programs. The results indicate that companies should match order-winning and internal performance criteria, functional strategies, and dimensions of the manufacturing system. Trends in the management of manufacturing systems that result in improvement of the manufacturing performance include:

more quality control process awareness; the decentralization of quality control and planning processes along with the integrated design of a consistent manufacturing system; the creation of work cells throughout the plant. Maani et al. (1994) empirically investigate, within the manufacturing industry, the operational and strategic impact of improved process quality on operations performance and describe the construction of a model of process quality. The research findings highlight that there is a favorable impact of enhanced quality in the form of improvements in productivity, in-process inventory, on-time delivery, and manufacturing cost. Drach (1994) explains how manufacturing standards - planning, performance evaluation, costing – can also be used to managing efforts towards optimizing the overall plant cost performance. Prasad (1995) presents a structured approach to continuous improvement - or in a larger sense, what is described as product and process optimization (PPO) - which includes, in addition to change management, a set of metrics and measurements. Dumond (1995) investigates the quality improvement programs carried out in ten US manufacturing firms and highlights that activities were pursued in each of the eight critical dimensions of quality management - training, employee involvement, process improvement, quality documentation, quality leadership, quality measurement, customer focus, and supplier quality management - but the scope and range of these activities varied widely. He concludes indicating that most of the organizations' efforts were focused on providing training and employee involvement, and that the visible commitment of top management was still seriously lacking. Prasad (1995) presents a structured approach to product and process optimization for manufacturing and service industries. Choi and Liker (1995) study the roles of process orientation and frequency of communication involving workers on the implementation of continuous improvement in seven US manufacturing companies. Ong (1997) presents some corrective actions which created a positive impact for a small made-to-order manufacturing company that, unlike large companies which are capable of applying just-in-time philosophies to ensure high productivity gains, faced specific problems in production planning and control. Chapman and Hyland (1997) examine the results of work carried out on quality management and Continuous Improvement (CI) in 385 Australian manufacturing companies, focusing in particular on aspects such as: the main motives for implementing a CI strategy, the most frequent content in CI processes, the supporting mechanisms for the change process involved, and the tools used to ensure the success of the change process. Vokurka et al. (1998) present a survey conducted amongst US-based companies on the use and performance implications of various methodologies to optimize the manufacturing process such as Total Quality Management, Just-In-Time, Flexible Manufacturing Systems, Computer-Integrated Manufacturing, automated manufacturing, etc... . Gattiker and Boyd (1999) present an approach to identify core problems in the manufacturing processes before improvement efforts begin. Cagliano e Spina (2000) explore on an empirical basis the role of strategic priorities and past experience in driving the selection of manufacturing improvement programmes. Starting from the level of strategic alignment of the company's choices, they also provide guidelines in order to manage effectively the process of manufacturing strategy formulation and improvement programme selection. Swinehart et al. (2000) present and discuss the strategies and approaches focused on continual and rapid improvement that can be used to achieve “world-class” manufacturing status. Ahlstrom and Karlsson (2000) highlight the importance of decentralizing the decision making process early during manufacturing improvement initiatives. Khim (2001) tests the effects of successive incremental TQM and JIT improvement techniques on eighty-three US electronic plants. The results of his study indicate that investment in manufacturing technology enhanced JIT performance but inhibit TQM performance. Grunberg (2003) discusses a number of methodologies and techniques aimed at improving the effectiveness and efficiency of manufacturing operational activity - such as business process reengineering, total quality management and organisation development – in terms of how to find potential improvement areas, how improvement should be achieved and implemented, and what to analyse and how to measure in improvement work. Kennedy and Hyland (2003) compare the past use, payoffs and expected future use by large firms and SMEs of a range of advanced manufacturing technologies and improvement programmes as reported by manufacturing managers of 632 manufacturing organizations in a global survey. Narasimhan et al. (2005) investigate, via an empirical study within fifty-eight US “world-class” manufacturing organizations, manufacturing practices, dimensions of manufacturing performance, and their relationships, in an effort to develop new insights into operations strategy. They find that the analysis of the practices-performance relationships implies a “progression” of capabilities linked to specific performance gains. Zhang et al. (2006) investigate the impacts of Advanced Manufacturing Technology (AMT) and Operations Improvement Practices (OIP) on Flexible Manufacturing Competence (FMC) as a source of competitive advantage. The results of their study indicate that AMT has a strong positive impact on FMC when OIP are effectively implemented. Lee-Mortimer (2006) details the implementation of lean manufacturing at a UK-based electronic product manufacturing operation which enabled the organization to build on an excellent foundation of continuous improvement – which delivered a major culture change along with significant OEE and quality improvements, and to start the process of moving away from batch/queue-type of production to creating flow through the whole plant, reducing WIP and lead time, and improving productivity. Taj and Berro (2006) applied the principles of constraint management - to identify bottlenecks - and lean manufacturing - to identify waste - to reveal means of increasing productivity in an automotive assembly plant to satisfy customer demand and developing best practices for productivity improvement of operation lines. Thawesaengskulthai and Tannock (2008) address the issue of the selection of possible Quality Management (QM) and Continuous Improvement (CI) initiatives and their various possible permutations by presenting a method to analyse the programmes from the perspective of the pay-offs, or expected benefits. The method summarizes various pay-off categories, assesses their credibility, and displays the similarities and differences for six key initiatives: total quality management, six sigma, ISO 9000, business process reengineering, lean and business excellence. The differences between the claimed pay-offs for these initiatives are also identified, analysed and discussed. Finally, Cousens et al. (2009) develop and test a procedure to enable organizations to establish a competitive capability to manufacture flexibly. By combining case studies and survey researches, they identify key steps to improve manufacturing flexibility and propose a framework to match operational capabilities with desired dimensions of flexibility, mix and/or volume.

5.10.4 Integrated Programmes within Woodworking and Furniture Companies

In order to find a benchmark with the present research study, the last stage of the literature analysis was represented by the investigation of integrated programmes conducted to optimize the manufacturing operations and performance within woodworking and furniture organizations. The findings are presented in the following.

Vickery et al. (1995) carry out a research to investigate the various aspects related to time-based competition within the furniture industry. In their study they highlight that time-based competition is a competitive strategy that seeks to compress the time required to propose, develop, manufacture, market, and deliver a product. They argue that reducing cycle time can significantly impact firm performance and that when time is compressed, productivity increases, prices can be increased, risks are reduced, and market share is increased. Cassens and Bradtmueller (1996) explore the main characteristics of the US small woodworking organizations that manufacture wood products to individual or other company specifications. They report the results of an investigation conducted in 168 companies which highlighted the main features of the sector in terms of number of employees, geographic location, products manufactured, space requirements, wage rates and benefits provided, distribution channels, business and production costs, and educational interests. Patterson and Anderson (1996) present a survey of furniture manufacturers conducted to determine the level of use of statistical methods – such as Statistical Process Control (SPC) - for quality control in manufacturing operations, e.g. for assessment of part quality as it leaves a work station. The results of their survey show that most companies hold the operator at each work station accountable for the quality of parts leaving that work station. Ruddell and Stevens (1998) analyse the motivation for adoption of the ISO9001 Quality Management System and the demand for certified products within the US woodworking industry. They identified customer demand, improved quality perception, and competitive advantage as the main external factors which can affect the decision of an organization to pursue the ISO9001 accreditation and other product certifications. Huang and Mak (1998) present the results of a survey which determined the extent of familiarity with and use of Design For Manufacture (DFM) in the UK furniture manufacturing industry. Their research’s outcomes showed that several companies achieved, perceived, or expected a significant level of benefits. Embedding DFM activities in day-to-day operations was perceived by managers as the most effective way of implementing DFM while a high level of management support and training for a formal team was necessary for its introduction. Klassen (2000) highlights the benefits of the Just-In-Time methodology applied in furniture manufacturing companies. In particular, after field work and a survey, he observes the links between investments in the JIT technique and improved environmental performance in terms of pollution prevention, which, surprisingly, improved the delivery performance. Schuler et al. (2001) carry out a study on the competitiveness of US wood furniture manufacturers. Quesada and Gazo (2003) develop and validate a manufacturing system for construction of school furniture at both low capital investment and minimum cycle times. They initially analysed the economic feasibility of the proposed system configuration, established the equipment layout, and collected process-related information. The project was divided into four stages: product design, process design, implementation, and process control. Software was also designed to monitor process control activities such as production scheduling, inventory control, employee database, and quality control. Hunter et al. (2004) present a study on the application of lean production techniques within the furniture industry. In particular, they utilize the basic manufacturing philosophies and methodologies for the design and implementation of a lean production sub-assembly manufacturing cell. Their research highlights the flexibility of lean manufacturing which proves to be adaptive and cost-effective, to improve quality, and to be ergonomically correct for workers in the furniture manufacture sector. In another study, Gazo and Quesada (2005) present a review of competitive strategies adopted by US furniture manufacturers. They identify the main aspects of these strategies in: low-cost labor, efficient communication systems, increasing stability and government support, low production cost, imported hardwoods, foreign know-how and investment, aggressive promotion campaigns, quality marks, development of alternative materials, education of workers, and high productivity. Their study, finally, highlight that the manufacturers define critical success factors the customer satisfaction, the internal operations, the innovation and growth, and the shareholder satisfaction. Cao and Hansen (2006) explore the fast-growing Chinese furniture industry's recent development characterized by low-cost advantages and measure its innovativeness via a combination of qualitative and quantitative approaches. They assess the correlations among four key variables - innovation, competitiveness, company size, and export intensity. The results of their study suggest that Chinese furniture firms are pursuing innovation with equal focus on product, process, and business systems. Quesada-Pineda and Gazo (2007) present some statistical analyses which show a positive relationship between top-performing US furniture manufacturers and the use of the industry’s best manufacturing practices. Navarro et al. (2007) report on foresight methods used by the furniture industry of “high cost countries” to address the issue of maintaining the future competitiveness with respect to the competition coming from “low cost countries”. Toppinen et al. (2007) investigate the organizational structure, strategic orientation, and future goals of woodworking firms in north-western Russia, particularly focusing on sources of competitive advantage. In another research, Quesada and Gazo (2007) conduct a case study within the furniture industry to develop a methodology to help manufacturers determine and rank key internal business processes based on Critical Success Factors (CSF). They identify customer service, manufacturing management, quality and price of the products as CSF, and customer engagement, product operations and supply chain management as key internal business processes. Tammela et al. (2008) show that Time-Based Competition (TBC) strategies aligned to logistics can help furniture organisations respond appropriately and more quickly to the different needs and expectations of customers located around the globe. They collect data from various furniture companies located in Brazil, Denmark and Finland in order to investigate the extent to which TBC in a logistic-oriented approach has been taken on board, and how it is perceived in national contexts. Finally, Azouzi et al. (2009) present a case study carried out in a Canadian firm to investigate the agility of advanced manufacturing technologies (AMTs) in furniture enterprises, and explore the appropriateness of a typology framework that correlates the technology infrastructure of the enterprise with its manufacturing strategy. Their study suggests that enterprise performance can be maximized if the competitive priorities and the customization strategy put in practice are in conformity with the available technology.

5.11 Conclusions

As it can be deduced from the previous analyses, the review of the relevant literature on production and operation management highlighted a gap represented by the lack of documented improvement programmes conducted in manufacturing organizations operating within the woodworking and furniture sectors and focused on the specific improvement techniques and tools applied in this research project. If such integrated programmes have been carried out in organizations within these sectors, the relevant literature does not document them. The results of the literature investigation, therefore, emphasized the opportunity for the objectives of this study to fill the existing gap in the literature by analysing the issues faced and the results obtained through the present research, which is used as a case study representative of specific manufacturing improvement programmes performed in organizations operating within the woodworking and furniture industries.

6 Implementation of the Integrated Improvement Programme

At the start of the research programme the business model, the competitive market, the product range and the manufacturing environment were unknown to the researcher. However, the researcher was able to provide a diagnosis of the manufacturing situation before the start of the improvement programme through a detailed analysis of the production processes and systems in place in the various departments which allowed him and the management to understand more in depth the manufacturing constraints the company was experiencing at the time which were preventing the organization from achieving a competitive edge in the market. By conducting a thorough assessment of the existing production processes through visual observation of the work activities, analysis of the manufacturing data available and regular discussions with the shop floor operators and team leaders, it was possible for the researcher to identify, within the main areas which needed improvements and targeted by the knowledge transfer partnership programme, the causes of the various constraints which were causing issues on the shop floor such as, as already mentioned, high levels of waste and rework, long lead-times, high levels of inventory.

Then, by starting at the company's objectives and by understanding the factors contributing to the measurements, the implementation of improvement techniques and proper measurement systems was undertaken and solutions were developed to allow the company to achieve its goals of increased capacity, reduced rework and reject costs, decreased work-in-progress and lead time. The next chapters will describe the manufacturing improvement techniques and methodologies carried out in the shop floor in order to tackle the issues.

As mentioned already mentioned in one of the previous chapters, the tasks undertaken to accomplish the purpose were as follows:

- Implementing a Quality Management System ISO9001:2000 and gaining accreditation,
- Introducing manufacturing Key Performance Indicators (KPIs),
- Carrying out Work Method Study and implement improvements,
- Performing a Machinery Capability Study for each product line,
- Carrying out Value Stream Mapping and Manufacturing Process Software Simulation,
- Implementing an enhanced manufacturing planning tool in the shop floor,
- Developing a Quality Function Deployment study (QFD), and
- Performing Failure Mode and Effect Analysis (FMEA) and implements improvements.

The study will then illustrate the results and improvements achieved after the completion of the 2-year project by presenting some of the qualitative and quantitative data gathered during and after the techniques implementation. Finally, the research will focus on discussing the general applicability within the woodworking SMEs industry of the methods undertaken and the results accomplished. Figure 6.1 presents a Gantt-chart highlighting the timescale of the various stages undertaken during the overall KTP project.

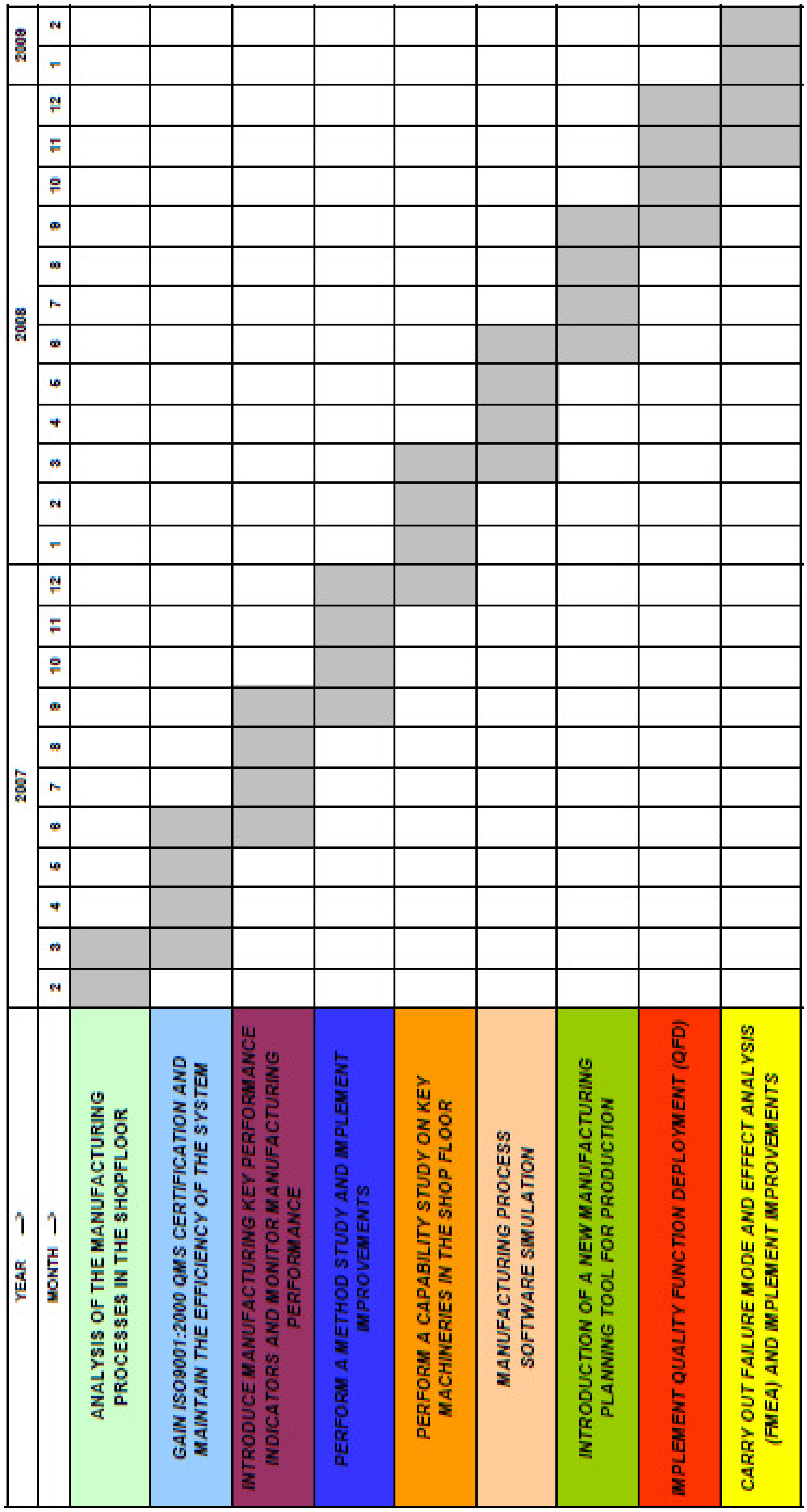

Figure 6.1 – Project Gantt-chart highlighting the task timelines

6.1 The Factory Floor: Layout and Material Flow

In order to better understand the various tasks carried out to complete the integrated improvement programme, first it is necessary to give the reader an overview of the factory floor layout and material flow, highlighting the manufacturing departments and the production process sequences of the different product ranges. As already mentioned, the core activity carried out at the company was based on various colour Medium-Density Fibreboard (MDF) and Melamine-Faced Chipboard (MFC) processing with the final aim to assemble and sell to customers finished products such as fire surrounds, kitchen units, furniture units and other components. Figure 6.2 shows the factory floor layout indicating the manufacturing macro areas and the various production processes by highlighting the material flows. As it is possible to notice in the figure, the manufacturing departments are as follows:

- Raw Material Stock
- Machine Shop 1
- Machine Shop 2
- Membrane Press
- Polishing Shop
- Surround Assembly
- Furniture Assembly
- Fire Fitting
- Kitchen Assembly
- Packing
- Distribution or Stock

The green arrows indicate the flow of components of the surround lines, whereas the red arrows show the flow of parts of the furniture and kitchen lines.
As the figure shows, the surround components were usually processed throughout the production departments according to the following common path:

0 - Raw Material Stock
1 - Machine Shop 1
2 - Machine Shop 2
3 - Surround Assembly (Cabinet Shop)
4 - Polishing Shop
5 - Fire Fitting
6 - Packing
7 - Distribution or Stock

The furniture and kitchen parts were usually processed according to the following department common sequence:

0 - Raw Material Stock
1- Machine Shop 1
2 - Machine Shop 2 or Membrane Press
3 - Furniture Assembly
4 - Packing
5 - Distribution or Stock

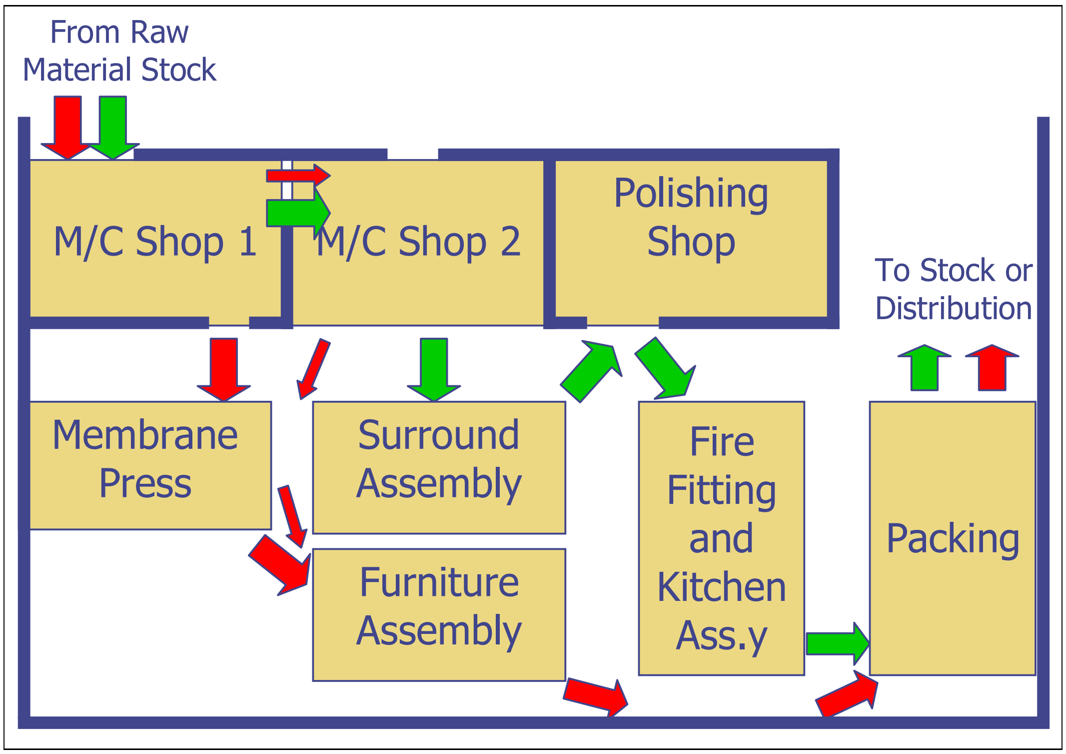

Figure 6.2 –Factory floor layout and "average" material flow

Figure 6.3 illustrates the Machine Shop 1 lay-out and the actual material flow. As the figure shows, according to the product type, most of the surround components were usually processed throughout the machines in the following sequence:

0 - Raw material Stock
1 - Surround Beam Saw ("Homag – Holzer")
2 - Surround CNC Machine ("Weeke")
3 - Edge Bander Machine ("Homag")
4 - Machine Shop 2

According to the product range, most of the furniture and kitchen parts were usually processed in the following machine path:

0 - Raw Material Stock

1 - Furniture Beam Saw (“Homag – Holzer”)

2 - Furniture CNC Machine (“Materwood”)

3 - Edger Machine

4 - Machine Shop 2

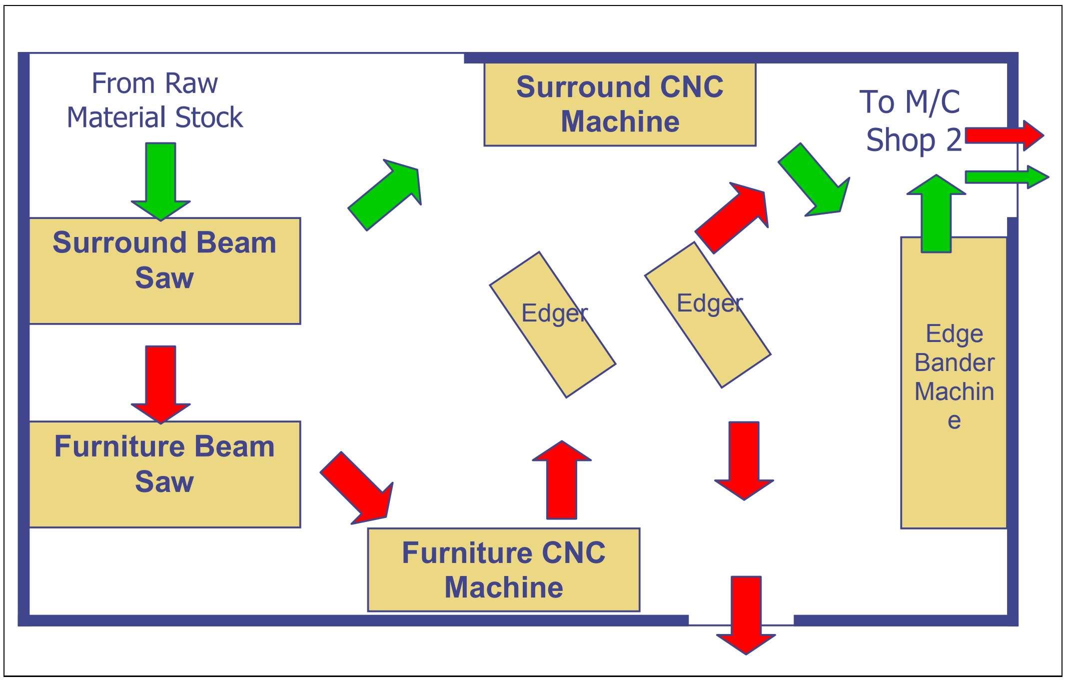

Figure 6.3 – Machine Shop 1 lay-out and “average” material flow

Now that the department layout, material flow, and production processes for the main product lines have been explained in details, it is possible to start deepening the various tasks carried out to achieve the main goal of the programme, i.e. improving various aspects of the overall manufacturing performance of the organization.

6.2 ISO9001:2000 Quality Management System Implementation

At the start of the improvement programme, the ISO9001:2000 Quality Management System accreditation with "BSI", as previously explained, was deemed by the company's management to be a strategic factor and a business priority for the company in order to entry into a number of new markets. As a result of this urgent need, a common decision was taken with the management to focus on this particular task since the very beginning of the project.
As a consequence of this agreement, the overall project plan initially elaborated slightly changed in terms of timescales, the main change being that the ISO9001:2000 Quality Management System, whose development was originally scheduled spread all over the duration of the whole project - 24 months, was then planned to be implemented since the start of the project and for the following four months, until the final accreditation audit. Hence, from a timescale point of view, all the other project stages "shifted onwards".

6.2.1 Main Stages of the Task

The phases followed during the implementation of the ISO9001:2000 Quality Management System are described in the following:

- analysis of all the different processes and procedures currently in use at the company;
- carried out a "gap-analysis" in order to determine the processes to be modified or introduced to comply with the ISO9001:2000 standard;
- introduction of new procedures and modification of existing procedures according to the findings of the "gap-analysis" carried out in the previous stage;
- introduction of the necessary documentation to support the new and existing procedures in place (i.e. manufacturing process route cards, process specifications/operating procedures, document control procedures, product and process checklists, production control procedure, manufacturing process operations, despatch procedures, etc…);
- key performance indicators such as waste reduction and other efficiency gains implemented to monitor the performance improvements;
- key performance indicators redefined and updated, changes logged as appropriate and review dates agreed;
- final review of all process documentation performed and internal audits undertaken, liaising with BSI staff at the appropriate stages;
- final assessment of the ISO9001:2000 Quality Management System carried out;
- ISO9001:2000 Quality management System certification achieved leading to new sales in targeted markets.

6.2.2 A Process-based Approach

The quality system developed at the company has been built on a process-based continual improvement approach (as shown in Figure 6.4) which is typical of the ISO9001:2000 Quality Management System standard, and it is based on the “plan-do-check-act” principles:

- Plan: establish the objectives and processes necessary to deliver results in accordance with customer requirements and the organization's policies;
- Do: implement the processes;
- Check: monitor and measure processes and product against policies, objectives and requirements for the product and report the results;
- Act: take actions to continually improve process performance.

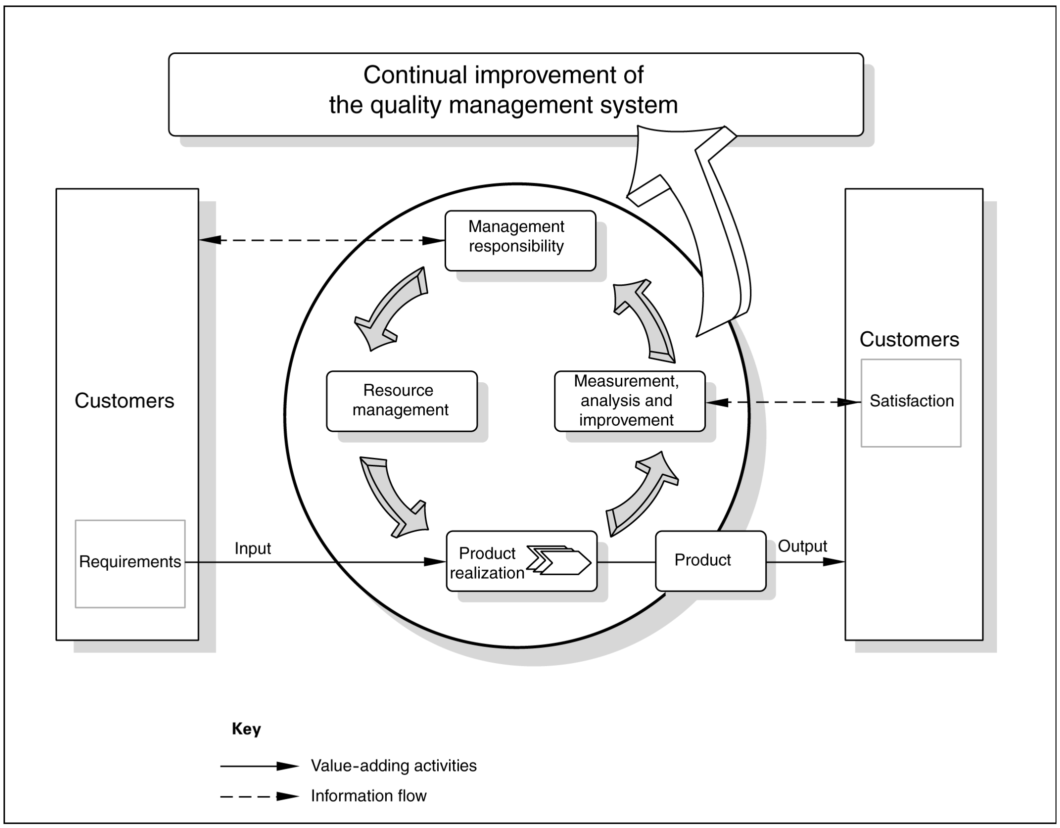

Figure 6.4 – The process-based Quality Management System approach typical of the ISO9001:2000 Standard

The quality system has been developed against the background of the already mentioned 8 management principles which proved to be fundamental when implementing the QMS by leading the business towards continuous improvement:

- customer focus,

- leadership,
- involvement of people,
- process-based approach,
- systems approach to management,
- continuous improvement,
- factual approach to decision making,
- mutually beneficial supplier relationships.

6.2.3 Milestones

In particular, the main milestones during the implementation were represented by:

- BSI "Gap-Analysis" and follow-up actions;
- Management Review Meeting for final QMS documentation approval;
- Completion of an Internal Audit Programme;
- BSI Pre-assessment Review and follow-up actions;
- Final ISO9001:2000 QMS assessment.

6.2.4 Initial Implementation Analysis

When the improvement programme began, the Quality Management System implementation had already started since some procedures had been already developed and put in place by the Manufacturing and Quality Director. During the first weeks since the project start-up an initial study of the company's processes has been carried out. In particular, the analysis of the draft ISO 9001:2000 manual, procedures and record forms developed and proposed by the Manufacturing Director in the past months and the findings of a series of meetings and interviews with various personnel within the departments of the organisation has enabled to highlight staff perspective on key issues and some gaps in the documentation. This review, for example, allowed to integrate into the Quality System some of the existing documents such as the Product Design and Development Procedure and the related record forms, already put in place in the Research & Development department.

6.2.5 "Gap-Analysis"

At the beginning of the KTP research programme, a thorough analysis of the current implementation process became necessary to verify the progress and the effectiveness of the procedures already in place.

For this reason, a “gap-analysis” has been carried out with the assistance of the accreditation organisation – BSI, and discussions took place on the scope of highlighting issues and weaknesses and pointing out different opportunities of improvement of the Quality System in-progress development in order to achieve the final ISO 9001:2000 certification. A brief overview of the procedures indicated adequate control, although it was found that some processes achieved only partial compliance with the requirements of the standard. In particular, the main findings of the “gap-analysis” are illustrated in the following:

- The Quality Management System organization chart was included within the manual showing lines of responsibility and authority from the level of the chairman down to the process operators.

- The Quality Policy was created and also documented within the manual, and it was considered appropriate for the needs of the company and its customers; management commitment to comply with requirements and their policy on continuous improvement was also included; a proper framework existed which included a set of generic quality objectives; the Quality Policy was posted on the company's notice board and it was intended to be included the employee handbook as well.

- The system defined the Management Representative as the Manufacturing Director with the researcher in the role of the Process Quality Engineer as the Nominated Deputy.

- Management review activities, in line with the requirements of the standard, were defined in the manual and were supported by an appropriate procedure; this process was not yet implemented although the first review was intended to take place in the following month; it was recommended that part of this review should include the identification of appropriate quality objectives at relevant levels of the business; these should be linked directly to the framework as defined in the Quality Policy; it was also recommended that the data generated should eventually be used to identify realistic targets against which future performance should be measured.

- The communication processes was also identified in the process interaction flow diagram.

- The Policy on Internal Audits was clearly defined in the manual and supported by a relevant procedure; the audit process was not yet commenced and some time was spent during the assessment discussing the principles behind effective process based auditing techniques and audit planning; BSI also provided the company with a matrix which was of use when planning audits to ensure that adequate coverage was given; it was hoped that auditor training would have been completed within the following months and that the audit programme would have commenced within the next weeks; it was also proved that the need to maintain auditor impartiality when conducting audits was fully understood by the company.

- The Document Control and Quality Record Procedures were in place and appeared to be operating; some discussions took place on the importance of ensuring adequate control on electronic documents and documents of external origin.

- In relation to customer focus, procedures were in place which defined control of receipt and review of customers requirements through production control and scheduling to works orders and also the use of shop floor documentation to control and monitor the production processes; as far as customer feedback and customer satisfaction monitoring were concerned, the management team was to discuss appropriate methods of capturing data from customers on a proactive basis at the next management review; the customer complaints appeared to be controlled in line with procedural requirements and data was available which would have been reviewed at the management review for trends etc….

- Procedures existed which defined control of corrective and preventive action inclusive of control of non-conforming product; BSI was also advised that approximately two months of data was available and this would have also been reviewed and analyzed at the management review meeting.

- Of significant importance was the Product Design and Development Procedure and, as a result, in-depth process flow diagrams were developed which were very concise in their content; the overall content of these diagrams appeared to address all the sub clauses of the relevant chapter of the ISO9001:2000.

- Discussions took place about the purchasing process - a need for identification of appropriate criteria for selection, evaluation and re-evaluation of suppliers was identified and needed to be addressed; the company was also reminded of the need to retain records of appropriate evaluations and associated actions; no concerns were identified associated with purchasing data or verification of purchased product.

- Some discussions took place on management of resources - various types of old and new production machines were at that time being used by the company and these were maintained based on a breakdown system; information was however being collected which provided for effective review for purposes of identification of planned maintenance if deemed appropriate.

- Determination of the employee competence was achieved by either definition on job descriptions and delegation of specific responsibilities within system procedures and discussions at appraisals; skills matrices were used by management which gave exposure to all human resource and their competences; at that time, these were only used in production; it was however planned to expand this practice company wide; training needs were identified through the appraisal process and also as a result of management review of the skills matrices; induction training also included communication of quality awareness.

6.2.6 "Gap-Analysis" Follow-up Actions

The "gap-analysis" highlighted opportunities to improve and fill existing gaps in the Quality Management System in the short-term. To this purpose, an ongoing review of the Quality System has been undertaken focusing the efforts on the improvement of the issues and weaknesses that have been identified during the "gap-analysis". In particular, the existing Documents Control Procedure has been integrated, as required by the Standard, with a list of all the internal and external controlled records and documents critical to the operation of the Quality Management System and that somehow had an impact on the processes of the company. Moreover, a procedure related to the non-conformances detected by the customers on products manufactured and delivered by the company is being created according to the findings of a meeting with the relevant customer management department Director. The "gap-analysis" follow-up activities carried out are summarised in the following:

- Integrated "Non-Conformances and Corrective Action Procedure" related to non-conformances detected internally by employees and externally by customers;
- Completed "External and Internal Document and Change Control Procedure" and "Records Control Procedure" to ensure adequate control of all documents of internal and external origin;
- Created a Customer Feedback System to assess the level of customer satisfaction;
- Created "Management Review Procedure";
- Integrated "Purchasing Procedure" and developed a Supplier Assessment and Re-Evaluation Method through the identification of appropriate criteria;
- Created "Sales Order Entry Processing Procedure";
- Issued "Machine Shop Process Procedure", "Fire Assembly Procedure" and "Fitting Assembly Procedure";
- Completed and Re-Issued "Internal Audit Procedure";
- Issued "Preventive Control Procedure".

6.2.7 Internal Audit Programme

A 40-hour Internal Audit training course has been undertaken with Granger's Consultancy Services in order to gain knowledge on how to plan, perform and report internal audits to monitor the Quality Management System and how to take corrective actions to best effect. Following the course, a 2-year internal audit programme has been started within all the departments as required by the standard. In particular, two internal audits have been conducted in the Research&Development and Administration departments and some issues have been highlighted and consequently addressed through a proper corrective action plan.

A summary of the Internal Audit-related activities carried out by the researcher is detailed as follows:

- 40-hour Internal Auditor Training Course undertaken with "Granger's Consultancy Services";
- 2-year Internal Audit Plan developed (Gantt Chart) covering all Departments;
- Internal Audit in the Research&Development Department carried out;
- Internal Audit in the Administration Department carried out;
- Created Checklists and Final Reports;
- Raised some Non-conformances and minor Observations;
- Created Corrective Actions Plan;
- Created QMS Gantt Chart and Action Diary in electronic format stored in the shared drive and available to all employees.

6.2.8 Management Review Meeting

A Management Review meeting has also been carried out by the Quality Department represented by the researcher (within the role of Quality Process Engineer) and Manufacturing Director with all the company's Directors (Sales, Operations, Finance and Marketing) and the Chairman to describe the ISO9001:2000 Standard requirements, involve the Board in the management of the System and spread the Quality-culture across all the organization. The main points discussed during the meeting in order to review in detail the Quality Management System covered the following topics:

- ISO9001:2000 standard requirements;
- Quality policy;
- Main document components of the QMS (Quality Manual, Procedures, Training Manual and Employee Handbook;

- Customer feedback, customer complaints and customer satisfaction;
- Existing process performance indicator values for the current semester;
- Internal audit progress and 2-year plan;
- Training data;
- Quality targets and objectives;
- Non-conformances and corrective actions;
- Preventive actions;
- Agree and establish the departmental quality objectives;
- Changes in the business which could affect the Quality Management System,
- Resource requirements to maintain and improve our Quality Management System;
- General review of the Quality Management System to ensure suitability, adequacy, and effectiveness;
- Final issue of all the Quality Management System documents and records presented to the chairman and to all the directors for approval and signature.

6.2.9 Pre-assessment Review and Follow-up Actions

A “pre-audit” review was also carried out with the assistance of BSI with the aim of determining the Quality Management System’s adequacy for the final assessment and to ensure its effective planning. The review drew attention to two issues regarding the Purchase Process and the drawings management system in the Machine Shop and in the Research&Development Department. As a consequence of this, the relevant procedures have been amended and a supplier assessment system has been developed, detailed and integrated into the Purchase Procedure and put in place within the Purchase Department.
Other minor issues identified by BSI and the Quality Department have been also dealt after the pre-assessment review audit was carried out in order to fully comply with the requirements of the ISO9001:2000 standards and to succeed in attaining the final accreditation.

6.2.10 Final Structure of the Company’s Quality Management System

The JRG Group Quality Management System applied to the design, manufacture and supply of bedroom and kitchen furniture, fire surrounds, and other associated MDF products. It also included the assembly and supply of electric fires and suites. The company’s Quality Management System has been developed following the criteria of the ISO9001:2000 Standard (Figure 6.5).

1-3 Scope
4 Quality management system
4.1 General requirements
4.2 Documentation requirements

5 Management responsibility
5.1 Management commitment
5.2 Customer focus
5.3 Quality policy
5.4 Planning
5.5 Responsibility, authority and communication
5.6 Management review

6 Resource management
6.1 Provision of resources
6.2 Human resources
6.3 Infrastructure
6.4 Work environment

7.1 Planning of product realization
7.2 Customer-related processes
7.3 Design and development
7.4 Purchasing
7.5 Production and service provision
7.6 Control of monitoring and measuring devices

8 Measurement, analysis and improvement
8.1 General
8.2 Monitoring and measurement
8.3 Control of nonconforming product
8.4 Analysis of data
8.5 Improvement

Figure 6.5 – The structure of the company's Quality Management System as required by the ISO9001:2000 standard

The System aimed at describing how the objectives of continually improve its customer service and meet its customer's expectations were implemented through identified responsibilities, written procedures and regular reviews. It has also been amended and developed to reflect changes in practice, products, specifications, standards, and, when necessary, to meet specific customer requirements. Furthermore, the agreed quality policy of the company was to conform to customer requirements by establishing and maintaining an environment which encouraged continuous improvement from the employees and the suppliers. Appropriate Quality objectives have also been set and reviewed by the management. These included:

- To recognise that the team of employees build the quality into our products and services;
- To provide the necessary information, training and support to enable the employees to achieve the levels of competence required;
- To ensure that all the products and services have the appropriate level of specification and performance standards to fully meet the customers requirements;

- To pursue, in liaison with the suppliers, continuous improvements in the products, materials and technology so as to continue to satisfy the expectations of the customers;
- To continue to develop our product range to meet the changing demands of the market place being served;
- To establish appropriate quality objectives relevant to customer and business needs;
- To conform to the requirements of ISO9001:2000 standard.

Figure 6.6, finally, shows the information and process flows documented within the structure of the company's Quality Management System.

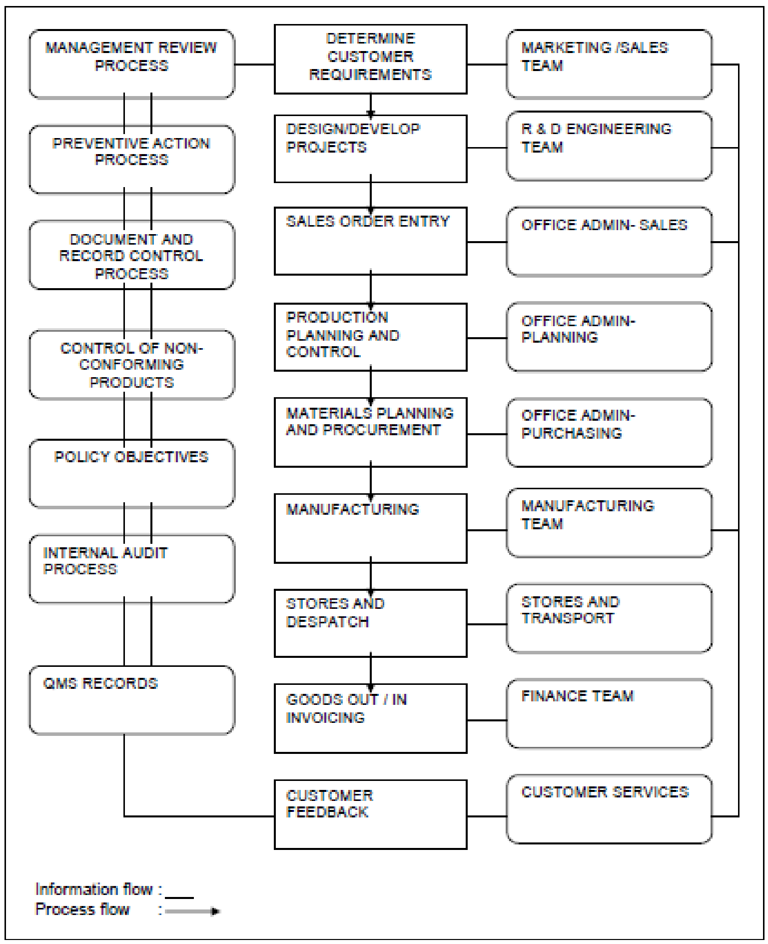

Figure 6.6 – The company's Quality Management System process chart

6.2.11 Final Assessment

Finally, following a two-day audit with BSI, the processes in place have been recognised as fully complying with the requirements of the ISO9001:2000 standard and the company achieved Quality Management System certification.

Figure 6.7 shows the ISO9001:2000 certificate of registration of the company.

Certificate
of Registration

QUALITY MANAGEMENT SYSTEM - ISO 9001:2000

COPY

This is to certify that:

JRG Group Ltd
3 Crompton Way
North Newmoor Industrial Estate
Irvine
Ayreshire
KA11 4HU
United Kingdom

Holds Certificate No: **FM 516103**
and operates a Quality Management System which complies with the requirements of ISO 9001:2000 for the following scope:

Design and manufacture of bedroom and kitchen furniture, fire surrounds and associated MDF products. Assembly and/or supply of electric fires and suites.

For and on behalf of BSI:

Managing Director, BSI Management Systems (UK)

Originally registered: **02/07/2007** Latest Issue: **02/07/2007** Expiry Date: **02/09/2010**

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Management Systems

Figure 6.7 – The ISO9001:2000 certificate of registration of the company

6.2.12 Maintenance of the Quality Management System

After the company accomplished the final ISO9001:2000 accreditation, the researcher was involved, along with the Manufacturing Director and other relevant personnel of the various departments, in the effective maintenance of the Quality management System. To this purpose, BSI conducted at regular 6-month intervals external audit to verify the continuous effectiveness of the QMS procedures in place within the organization.

In particular, during the improvement project, 4 external audits have been successfully carried out with the issue of minor non-conformances and observations.

6.3 Manufacturing Key Performance Indicators Implementation

Since the first months after the start of the integrated improvement programme at the company, a manufacturing performance evaluation process was put in place within the shop floor departments through the implementation of various key performance indicators with the aim of monitoring different aspects of the production processes of the organization.

The researcher was involved on a daily basis in the shop floor in manufacturing activities regarding production planning and management working alongside the Manufacturing Director and Operations Director. In particular, he took part regularly to activities such as issuing the production planning spreadsheets to the departments' team leaders, issuing the product cutting lines and production progress spreadsheets to the operators of the machine shop, and updating the product packing sheets.

This regular involvement facilitated the creation of production performance measures and the process of data collection within the manufacturing departments.

In particular, the collection and analysis of production efficiency data within the manufacturing departments of the shop floor focussed on information regarding:

- work-in-progress data in the individual production departments in terms of minutes and units left to complete the current job batches;
- key-gate data;
- actual manufacturing lead-time data of job orders in working days;
- actual vs. allocated job time data through the various machines and departments;
- raw material usage data (MDF/MFC board sheets);
- rework and reject data;
- first-time yield data for each machine and department;

6.3.1 Work-In-Progress Data

Figure 6.8 shows one of the three main production planning and control spreadsheets – one for each of the main product lines (M10: furniture, S10: surrounds, K10: kitchen and other components), containing number of units and time data of all the job batches processed in the shop floor. These sheets were updated on a daily basis according to the data provided by the departments' team leaders at the end of each production shift. Work-in-progress data in terms of minutes and units were the automatically calculated and displayed for each machine and departments at the bottom of these spreadsheets so that the information was up-to-date every day. As it will be highlighted in one of the following chapters, the three spreadsheets were in place and used in the shop floor by the manufacturing staff only at the start of the project. At a later stage of the programme, in fact, they have been replaced by an enhanced spreadsheets (P10) which gathered all the product lines manufactured by the company and which also automatically displayed updated information regarding the machines and department capabilities in terms of minutes available.

M10	as at 9 a.m. (Bold = Cutting lines issued)											Monday 12 November 2007			
ORDER NO	RANGE - COLOUR	QTY	CUT	CNC	Edge Band	Transfer Foil	M/c Shop	Press	Assembly	Built	Update	Date	Sheets required	Units /day	Packed
WEEK 47															
FV PO8904	VIENNA - BEECH	20	V	V	V	V	8	V	351			19-Nov	5		19
OCHFW PO8905	OCHIL - FRENCH WALNUT 179	51	319	537	74	V	62	428	818			19-Nov	52	71	
	Copperworks kitchen doors	125										22-Nov			
	Copperworks Kitchen Carcasses	95										22-Nov			
PAFW PO8916	PANAMA - FRENCH WALNUT	3	19	23	V	18	20	V	66			22-Nov	2	223	
PABE PO8917	PANAMA - BEECH	1	2	3	V	3	V	V	7			23-Nov	1		
IRBE002	IRVINE - BEECH	3	16	25	V	14	12	5	63			23-Nov	1		
TY PO8918	TRANQUILITY - HIGHLAND OAK 6	6	12	30	V	V	V	24	24			23-Nov	2		
BR25691	BRENTMERE - MESSEYNE	428	259	1356			120	517				23-Nov	25		
PO23374	OMAR - MAPLE	17	75	83	V	70	38	V	254			23-Nov	5		
E8637	VANITY	8	40	76	20	V	48	56	140			23-Nov	3		
NVH2611	NORTHVIEW KITCHEN	10										23-Nov		473	
WEEK 48															
	JURA - OPERA WALNUT	57										27-Nov		57	
	Copperworks kitchen doors	125										28-Nov			
	Copperworks Kitchen Carcasses	95										28-Nov			
	JURA - OPERA WALNUT	50										28-Nov		270	
	JURA - OPERA WALNUT	50										29-Nov		50	
	IRVINE - FRENCH WALNUT	1										30-Nov			
WEEK 49															
D050	MYSTIQUE - FRENCH WALNUT 684	57	1605	2653	321	V	256	2356	3938			03-Dec	67	57	
"	MYSTIQUE - FRENCH WALNUT	50		all included above								04-Dec		50	
"	MYSTIQUE - FRENCH WALNUT	50		all included above								05-Dec		50	
"	MYSTIQUE - FRENCH WALNUT	50		all included above								06-Dec		50	
"	MYSTIQUE - FRENCH WALNUT	50		all included above								07-Dec		50	
WEEK 50															
	HARRIS - BEECH ROUND	50										10-Dec		50	
	HARRIS - BEECH ROUND	44										14-Dec		44	
	Total number of unit on this list = 1496	QTY	BEAM	CNC	Edge Band	Transfer Foil	Machine	Press	Assembly	Built	STILL TO BE PACKED				PACKED
	TOTAL MINS	1496	2347	4786	415	105	564	3386	5661						
										0	1477				19
	WIP @ Machines			1456	1426	1334	1469	1435	0						

Figure 6.8 – The furniture manufacturing planning and control spreadsheet (M10)

Figure 6.9 shows, for each of the main product lines manufactured at the company, the inventory data collected in terms of units and minutes left to complete the ongoing job batches. As explained above, the data were gathered on a daily basis by updating the production scheduling spreadsheets for each relevant machine or department.

- M10 (Furniture)

Total number of unit on this list = 1496	QTY	BEAM	CNC	Edge Band	Transfer Foil	Machine	Press	Assembly	Built	STILL TO BE PACKED	PACKED
TOTAL MINS	1496	2347	4786	415	105	564	3386	5661			
									0	1477	19
WIP @ Machines			1456	1426	1334	1469	1435	0			

- S10 (Surrounds)

		QTY	BEAM	CNC	MACH	CAB	POL	FIT	PACK	STILL TO BE PACKED	PACKED
TOTALS	MINS		943	1529	6001	6669	4631	1853	2502		
TOTALS	UNITS	239	110	94	100	100	100	100	0	239	0
TOTALS	WIP	1264	110	94	100	100	100	100	0	714	

- K10 (Kitchens and Other Components)

Total number of unit on this list = 946	QTY	BEAM	CNC	Edge Band	Transfer Foil	Machine	Press	Assembly	Built	STILL TO BE PACKED	PACKED
TOTAL MINS		0	0	0	0	0	0	0			
									0	946	0
WIP @ Machines			388	388	388	388	388	388			

Figure 6.9 – Work-in-progress data for each product line at the various machines and departments

6.3.2 Key-Gate Data

Another work-in-progress type of indicator which was implemented within all the manufacturing departments was represented by the internal customer key-gate performance. It measured the overall number of jobs processed by the production departments for each week of the year. Figure 6.10 shows an example related to the surround assembly department (cabinet shop).

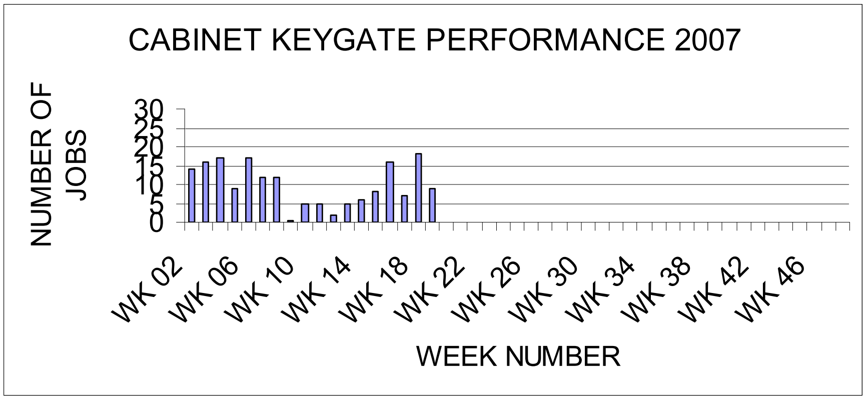


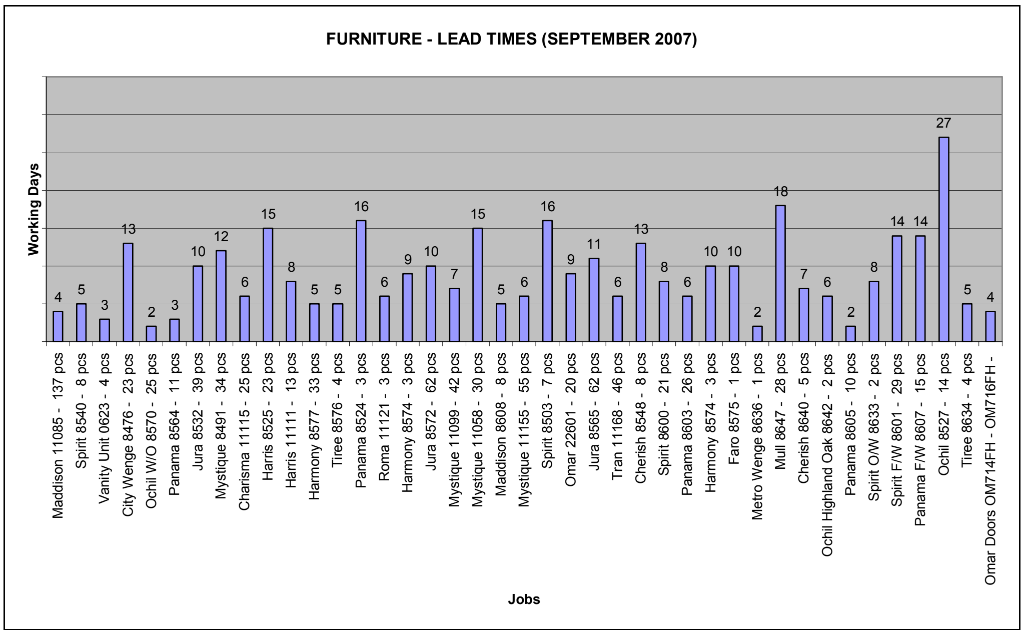
Figure 6.10 –Key-gate performance for the Cabinet Shop department (surround assembly)

6.3.3 Lead-time Data

Another important piece of information gathered in the shop floor was represented by the overall manufacturing lead-time of the various product ranges processed. Over a period of time, the manufacturing lead-time of the various product lines was measured by collecting data regarding the time elapsed in each department by the job batches since the time they arrived to the time they were completed and were moved to the following department. By adding up all these departmental lead-time values for each product range, it was then possible to quantify exactly the overall lead-time of the items processed throughout the factory floor since the very beginning of the production process – when the raw material in the form of relevant MDF or MFC board sheets were cut, up till when the products were packed and ready to be stored in stock or shipped to the customer. The lead-time data collected were then averaged each month for each of the product lines manufactured.

Figures 6.11 shows the actual and average manufacturing lead-time values of various furniture ranges measured during the first months of the research programme (mid 2007). Figure 6.12 displays the actual and average manufacturing lead-time values of various furniture ranges measured during the last months of the research programme (late 2008). It is possible to clearly notice how the average manufacturing lead-time values decreased from about 8 to about 5 working days towards the end of the research study as a consequence of the tasks and improvements implemented during the programme and described in the following chapters.

PRODUCT NAME	*JOB NO.*	*QUANTITY*	*START DATE (CUT)*	*FINISH DATE (PACKED)*	*LEAD TIME (WORKING DAYS)*
Ochil W/O	**8570**	**25**	**03/09/2007**	**04/09/2007**	**2**
Panama	**8564**	**11**	**31/08/2007**	**04/09/2007**	**3**
Jura	**8532**	**39**	**23/08/2007**	**05/09/2007**	**10**
Mystique	**8491**	**34**	**22/08/2007**	**06/09/2007**	**12**
Charisma	**11115**	**25**	**03/09/2007**	**10/09/2007**	**6**
Harris	**8525**	**23**	**21/08/2007**	**10/09/2007**	**15**



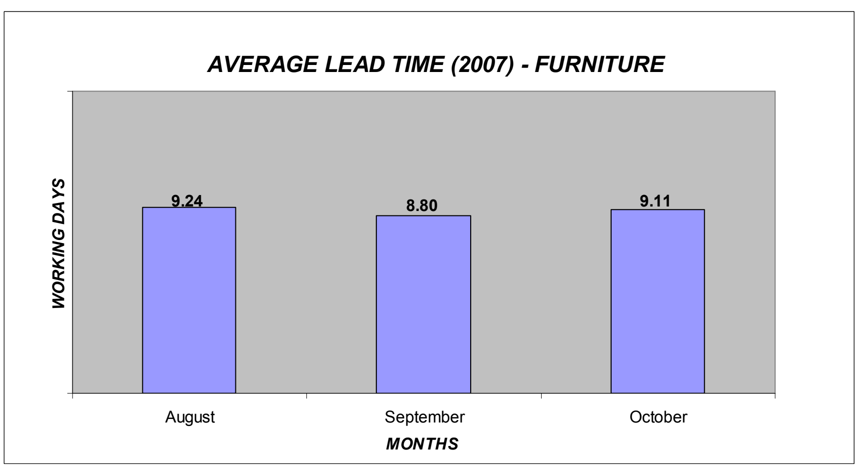
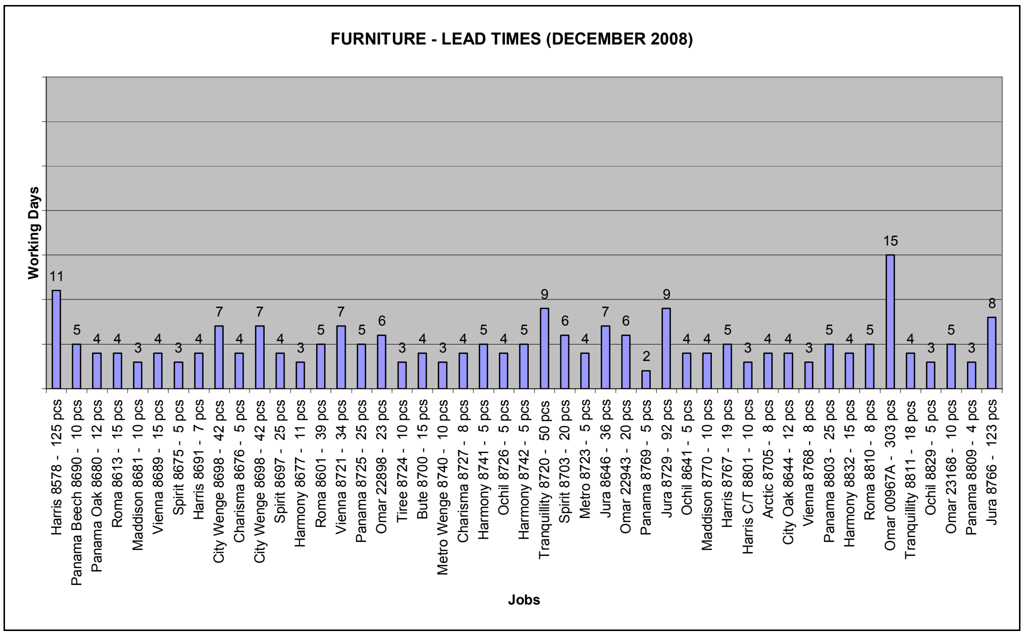


Figure 6.11 – Actual and average manufacturing lead-time of some furniture ranges measured during the first months of the research programme (mid 2007)

PRODUCT NAME	JOB NO.	QUANTITY	START DATE (CUT)	FINISH DATE (PACKED)	LEAD TIME (WORKING DAYS)
Omar	22943	20	08/12/2008	15/12/2008	6
Panama	8769	5	08/12/2008	09/12/2008	2
Jura	8729	92	09/12/2008	19/12/2008	9
Ochil	8641	5	10/12/2008	15/12/2008	4
Maddison	8770	10	11/12/2008	16/12/2008	4
Harris	8767	19	12/12/2008	18/12/2008	5



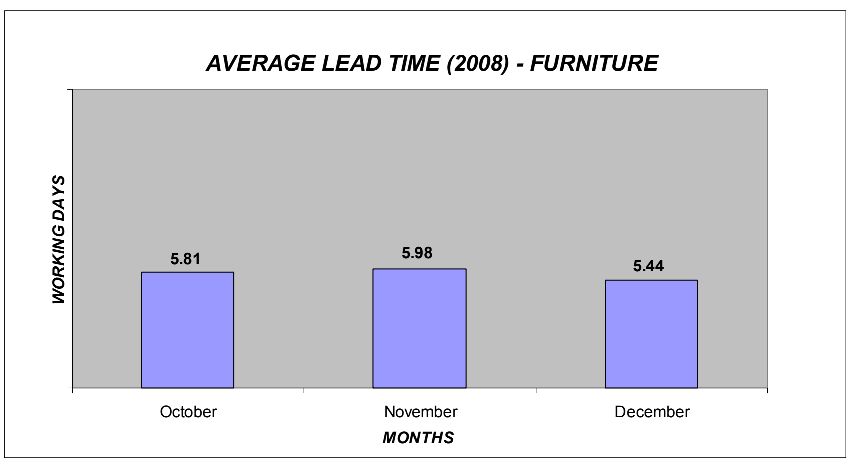


Figure 6.12 – Improved actual and average manufact. lead-time of some furniture ranges measured during the last months of the research programme (late 2008)

Finally, figure 6.13 shows the record form used within the machine Shop 2 department in order to collect the lead-time data for the surround ranges. The form highlights the allocated job time for each of the manufacturing processes and machines present in the department. It contains blank boxes to be filled in by the operators with the start and finish times for each of the job orders processed so that it was possible for the researcher to calculate the overall lead-time through the department

JOB PROGRESS

M/S 2 START						M/S 1						M/S 2											M/S 2 FINISH		
DATE	TIME	JOB No.	PRODUCT	COLOUR	QUANTITY	Saws	"Masterwood" CNC	"Weeke" CNC	Edge Bander	Curve Edger	Transfer Foil	Spindle	Chop Saw	Dim Saw	Manual Router	Pocket Router	Dowel Inserter	Multiborer	Mould Sand	Edge Sand	Face Sand	M/S 1 + M/S 2	DATE	TIME	DATE DUE IN CABINET SHOP
		PO11411	Bordeaux Surround	Red Mahogany	6	48		60	14	24		36		18		30				18	30	278			24/04
		PO2104TD	Prestige - Chimney Brea	Dover Stone	1	25		50														20			26/04
		PO11437	Marbella Surround	Pembroke Stone	3	33		39	12			21		9		15				24		153			27/04
		PO11454	Alicante Surround D047	Country Oak	6	48		36	19			48		6		30						187			28/04
		PO11457	Balletta Surround C050	Natural Oak	3	30		6				9	9	42							9	105			29/04
		PO11458	Cheriton Suite/stone	Dover Stone	12	96		30	34			120		72		48			48	66	12	526			30/04

Figure 6.13 – Lead-time data record form used within the Machine Shop 2 department

6.3.4 Job Time Data

Also associated to the job batches lead-time, other indicators were established within the manufacturing departments related to the daily and weekly measure of the overall actual against allocated job times.

Each day the difference between actual and allocated minutes was calculated for each machine taking into account only completed job batches. The daily overall difference was calculated too in order to estimate the discrepancy between the minutes planned for the day shifts according to the job types to be processed and the actual minutes achieved to complete those jobs. Finally, the values were also added up and compared on a weekly basis in order to evaluate more realistic and reliable figures in case the actual work minutes for some job batches were recorded by the operators the day after they were started if those jobs were not completed on the same day.

Figure 6.14 shows an example related to some data collected at the two beam saws in the Machine Shop 1 in which actual minutes are compared against planned minutes for cutting on a daily and weekly basis.

			Minutes (ONLY COMPLETED JOBS)								
									TOTAL		
			BEAM SAW 1			SAW 2			SAW 1 + SAW 2		
			Sheets	Actual	Δ	Sheets	Actual	Δ	Sheets	Actual	Δ
WEEK 03	Mon	12/01/09	348	410	62	277	290	13	625	700	75
	Tue	13/01/09	166	235	69	177	230	53	343	465	122
	Wed	14/01/09	305	305	0	397	400	3	702	705	3
	Thurs	15/01/09	86	86	0	0	0	0	86	86	0
	Fri	16/01/09	1567	1567	0	141	185	44	1708	1752	44
	Total		2472	2603	131	992	1105	113	3464	3708	244
	Planned		1860	1860		1860	1860		3720	3720	
	Δ		612	743		-868	-755		-256	-12	

Figure 6.14 – Actual against allocated job times at the 2 beam saws

The job time data for some machine of the Machine Shop 1 department were automatically collected by the machine itself by logging at the end of each day shift the progressing number of operating hours (application time the machine was actually working on a part) and the progressing number of parts processed. By comparing the number of operating hours and parts processed with the previous day shift values it was then possible to calculate the actual number of daily application time minutes and parts processed at the machine and the difference against the targeted values. Finally, weekly totals and daily average values were also calculated. Figure 6.15 shows the data logged by the "Weeke" CNC Machine.

"WEEKE" CNC MACHINE					
	TOTAL ACTUAL APPLICATION TIME			PARTS PROCESSED	
Date	Hours (progressive)	Mins/Day	Difference against target	Quantity (progressive)	Parts/Day
Tue 10/02/2009	6431.4	-	-	129154	-
Wed 11/02/2009	6439.9	510	95	129273	119
Thu 12/02/2009	6448.8	534	119	129557	284
Fri 13/02/2009	6457.2	504	314	129900	343
WEEK TOTALS		1548	528		746
DAILY AVERAGE		516	176		249
Mon 16/02/2009	6461	228	-187	129928	28
Tue 17/02/2009	6469.8	528	113	130195	267
Wed 18/02/2009	6478.1	498	83	130329	134
Thu 19/02/2009	6485.2	426	11	130407	78
Fri 20/02/2009	6492	408	218	130629	222
WEEK TOTALS		2088	238		729
DAILY AVERAGE		418	48		146

Figure 6.15 – Minutes and parts data collected at the "Weeke" CNC Machine

Finally, job time data have also been collected and used in particular department to compare the actual job time values against the allocated time and the actual lead-time - time elapsed since the time when the job order arrives in a particular department ready to be worked on until the time when it is ready to move to the following department.

Figure 6.16 shows an example of job time data gathered in the Machine Shop 2 where there were many machines and it was necessary to measure and compare actual and allocated job times as well as the overall lead-time through the department.

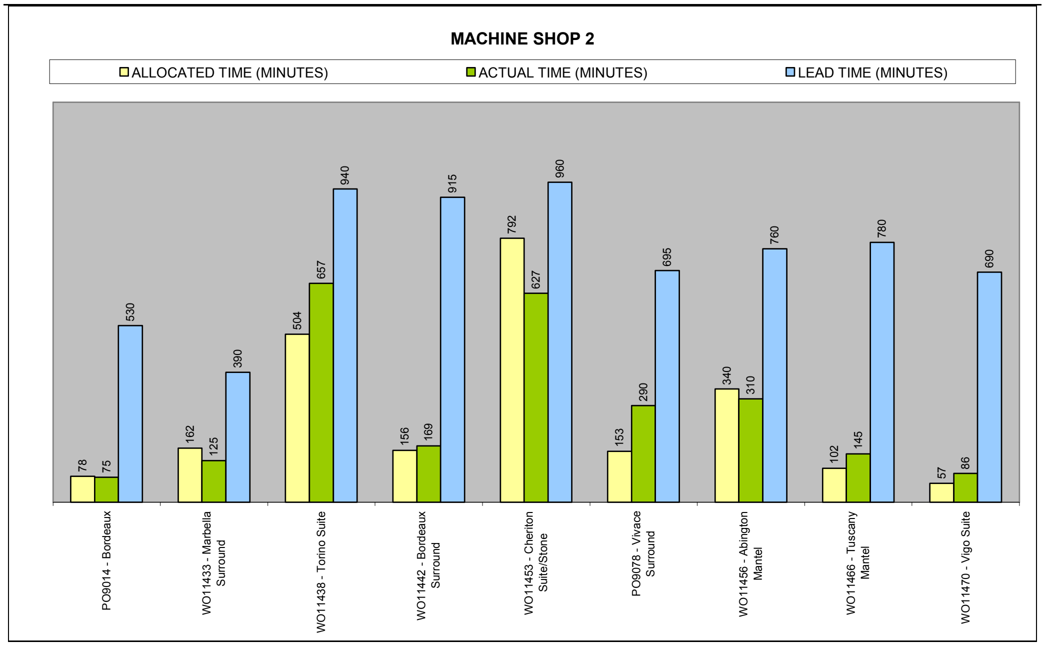


Figure 6.16 – Machine Shop 2 job time comparison for some surround job orders

6.3.5 Raw Material Usage Data

Finally, the researcher started also to monitor the actual usage of some raw material.

In particular, a data collection process began regarding the actual amount of board sheets used to cut the job batches of the various product lines. The data were gathered at the very start of the manufacturing process, i.e. at the beam saws by the Machine Shop 1 operators. The information collected was then compared against the values of board usage estimated for each job processed in order to optimize the material order planning phase and to provide more accurate product quotations to customers.

Figure 6.17 displays a comparison between actual and estimated board usage data for some furniture jobs processed at the beam saws in the Machine Shop 1.

The data gathered was also used during the work method study stage when analysing the operators cutting procedures and when optimising the cutting patterns by grouping and processing together the job orders cut with the same type of board, which allowed to decrease the amount of off-cuts and waste and to achieve better overall board yields.

BOARD USAGE ANALYSIS – FURNITURE								
Work Order	**Product**	**Q.ty**	**18 MDF double sided**		**3.2 MDF Plain**		**3.2 MDF Beech**	
			Est.	**Actual**	**Est.**	**Actual**	**Est.**	**Actual**
CH WO10041	Charisma	28	-	-	1.55	2	5.95	8
PO7940	Vienna	43	24.85	25	4.81	7	16.4	26
PO7946	Tropez	8	2.16	2.5	0.61	1	0.85	1
LA WO9991	Larisa	26	9.62	9	2.35	4	4.26	5
TI WO10025	Tiree	20	8.49	8.66	2.69	4	6.01	3
PO7943	Monaco	8	4.65	6	-	-	2.33	3
PO7918	Faro	13	4.79	5	1.14	2	2.3	3
PO7918	Faro	3	1.99	2	-	-	-	-
FA WO1007	Faro	15	5.67	6.50	1.49	2.5	2.82	1
PO7917	Roma	8	3.47	4	-	-	-	-
PO7915	Harris	20	5.06	5	-	-	-	-
PO7916	Jura	62	42.25	43	-	-	-	-
MO WO10059	Monaco	48	-	-	6.22	11	14.43	10
FV WO10030	Vienna	26	9.14	9	2.4	3	4.81	2
WO10052	Harmony	9	3	4	0.74	2	1.58	1

Figure 6.17 – Comparison between actual and estimate board usage data for some furniture jobs

6.3.6 First Time Yield Data

A fundamental data gathering process established within all the manufacturing departments of the organization was represented by the information collected regarding daily and weekly first time yield quantities for each job order processed.

These data have been gathered from the daily "Accepted Product Record" forms which were put in place within each production department when the Quality management System ISO9001:2000 procedures were established. These forms were completed by each of the production team leaders on release of products which met the quality requirements through their department. The information collected regarded the amount of items per job order completed without any faults detected in a particular department. The data gathered was then used to create a graph displaying the weekly percentages of first time yield passes in order to depict yearly trends for each production department and to compare the trends against the target set for the year. The target was then quarterly reviewed according to the actual trend achieved week after week.

Figures 6.18a and 6.18b display some of the first time yield data gathered in the Kitchen Assembly Department in 2007 and in 2008. The figures clearly show the improvements achieved in 2008 - when the first time yield percentage target of the department was increased from 90% to 95% - in terms of amounts of first time passes as a result of the implementation of some of the programme tasks.

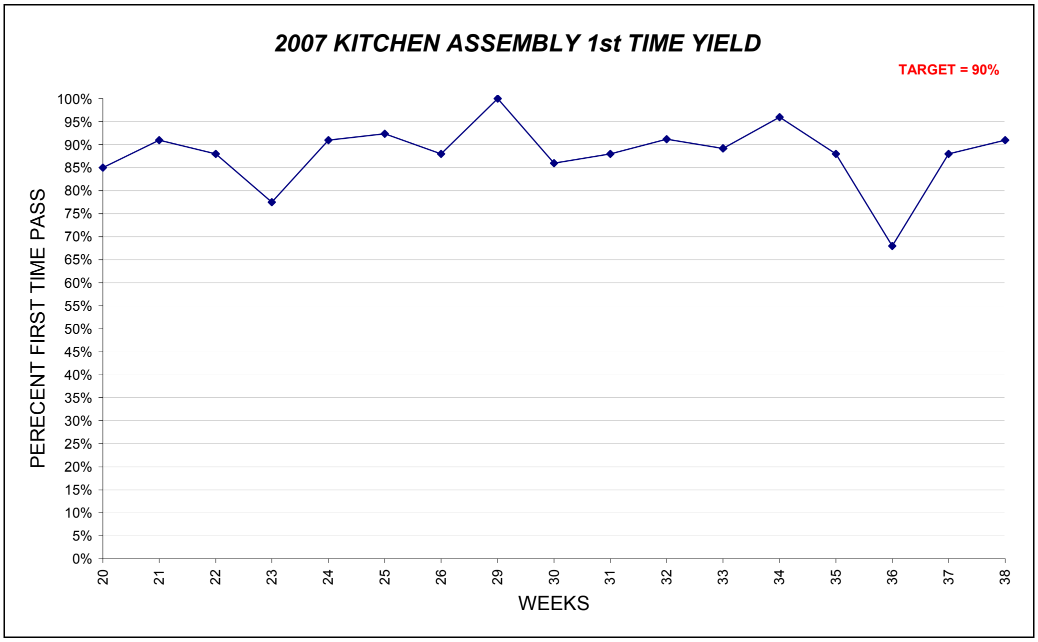


Figure 6.18a – First time yield data collected in the Kitchen Assembly Department in 2007

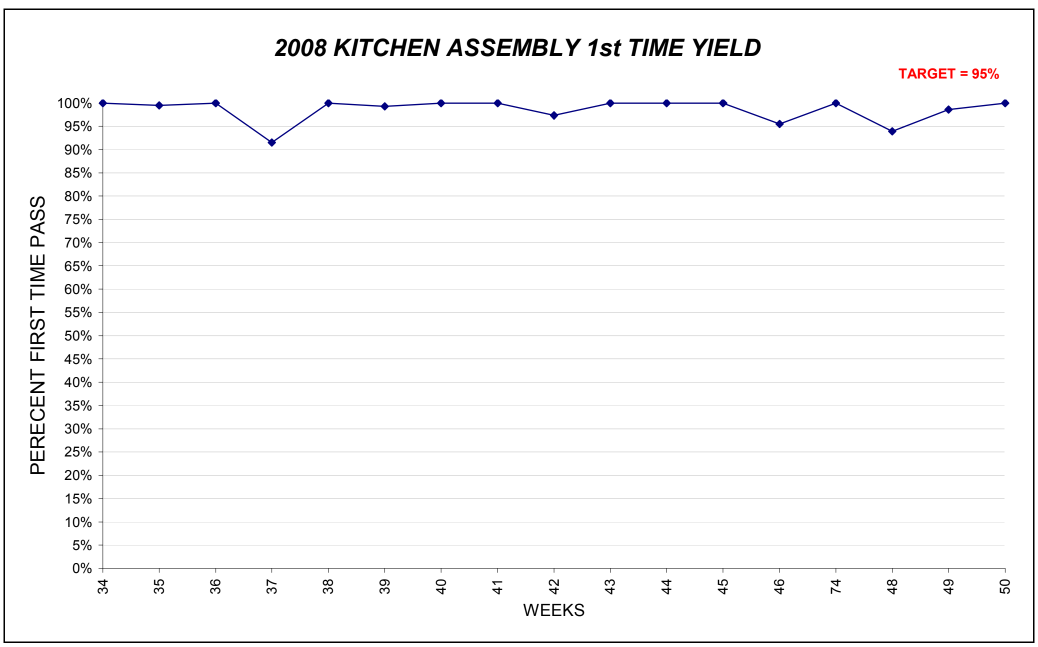


Figure 6.18b – First time yield data collected in the Kitchen Assembly Department in 2008

6.3.7 Rework and Reject Data

Other record forms regarding the types of fault detected were also put in place within the production departments in the shop floor during the implementation process of the Quality Management System ISO9001:2000. The information gathered was related to the specific reasons why a component or an assembled unit was rejected for rework or scrapped by a particular department. The data was then displayed in graphs per each department indicating the percentage of occurrence per each week of the year. Quarterly review meetings were also held with the Manufacturing Director and the shop floor team leaders with the aim of analysing the data collected and better understand the responsibilities of the faults. Figure 6.19 displays an example of the main fault codes (rejects and reworks – reworks are indicated with an “X” in front of the fault code) detected in the Furniture Assembly department.

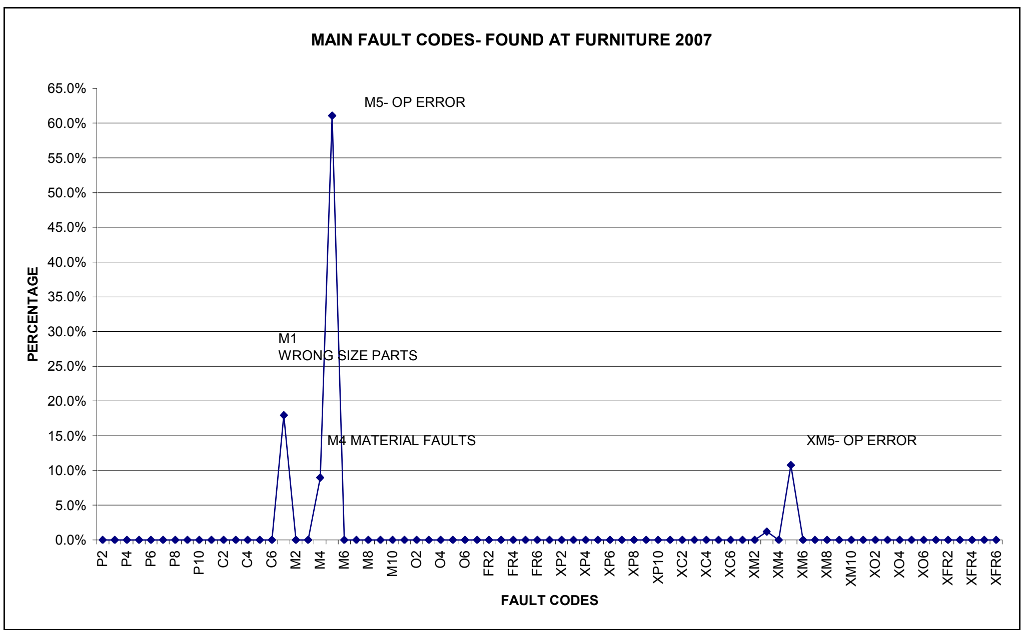


Figure 6.19 – Example of the main fault codes detected in the Furniture Ass.y dept.

The rework and reject data collected were then arranged on a weekly basis in graphs according to a “Pareto Analysis” of the percentage of occurrence of the fault codes, starting from the far left of the graph showing the most recurrent fault, as an example for the Kitchen Assembly department shows in figure 6.20. Figure 6.21 shows the fault codes used by the operators in the Kitchen Assembly department. It is important to notice that the data collected regarding reworks and rejects within the various production departments have been also used at a later stage as input information for the Failure Mode and Effect Analysis (FMEA) and the cost of quality tasks.

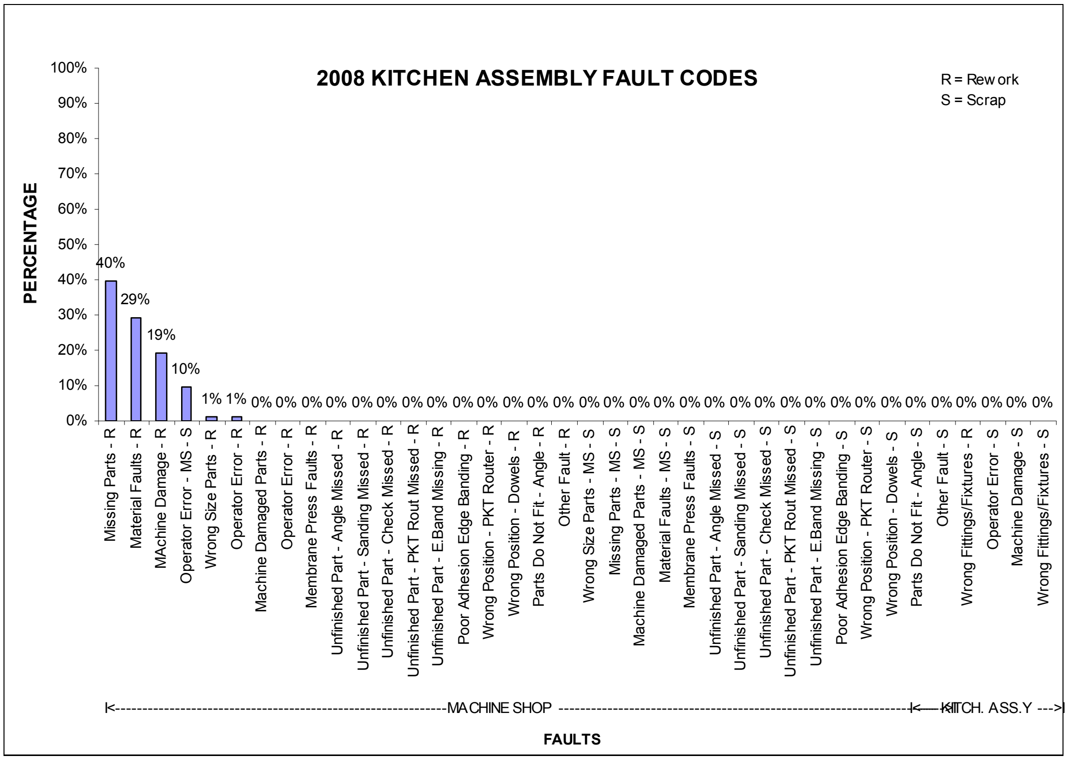


Figure 6.20 – Example of "Pareto Analysis" of the rework (R) and scrap (S) codes detected in the Kitchen Assembly department

Missing Part
Material Fault
Machine Damage
Operator error
Wrong Size Parts
Machine Damaged Parts
Membrane Press Faults
Unfinished Part - Angle Missed
Unfinished Part - Sanding Missed
Unfinished Part - Check Missed
Unfinished Part - PKT Rout Missed
Unfinished Part – EdgeBand Missing
Poor Adhesion Edge Banding
Wrong Position - PKT Router
Wrong Position - Dowels
Parts Do Not Fit - Angle
Other Fault
Wrong Fittings/Fixtures

Figure 6.21 – Example of fault codes for the Kitchen Assembly department

6.4 Work Method Study

The work method study task initially targeted the machine shop area of the factory and aimed to improve and enhance the performance of the operators working on the various machines. Then, some of the concepts learnt and put in practice within the machine shop area have been also applied to other manufacturing departments within the factory in order to investigate the work methodologies of the employees working on the various machines and ultimately, to optimize and streamline the overall production process. A work method study literature review was initially carried out in order to allow the researcher to improve his knowledge of the topic. The main reference and source of information used was represented by the book "Work Study" (R. M. Currie, Joseph E. Faraday – Pitman Publishing Limited – Fourth Edition). Work method study represented also one of the fundamental subjects which were used as input to carry out the process control procedures introduction and the machine capability study tasks at later phases of the overall improvement project implementation.

6.4.1 Main Stages of the Task

In the following are described the main phases carried out during the implementation of the work method study and the main outputs produced after the completion of each step:

- along with the production personnel - manufacturing manager and departments' team leaders, selection of critical operations in the shop floor, focusing first on the machine shop area, then extension of the study to other manufacturing departments;
- data collection and recording of the selected operations using standard method study techniques, e.g. through the creation and use of flow, activity, and process charts; videos were also recorded to investigate and compare the operators' methods of working;
- critical examination of the records and where appropriate carried out improvement of the existing work methods or development of new methods in agreement with the production departments' team leaders and the company's management;
- findings presented to the company's management;
- new procedures documented;
- incorporation of the new or enhanced methods into the work procedures with the assistance of the manufacturing director and production team leaders, at all times engaging with shop floor personnel;
- evaluation of the results after the implementation of the work method changes in the machine shop;
- continuous improvement procedures established to ensure the new or enhanced methods are maintained, including detailed process instructions.

6.4.2 Implementation

The work method study at first focused, as mentioned earlier, on some key machinery at the very beginning of the manufacturing processes in the machine shop, i.e. two beam saws and two CNC machines, with the ultimate goal of reducing the negative effects in terms of long production lead-times and high levels of inventory of some bottle-neck operations due to some poor work methods adopted by the machine shop operators.

The objectives of the study were represented by decreasing the job set-up times, the changeover times and all the other possible breakdown times in order to increase the machine available capacity in terms of running time so as to, ultimately, decrease the work-in-progress and the manufacturing lead time.

The methods applied with the purpose of achieving these goals were represented by:

- the implementation of better material flows,
- the maximization of the machine utilisation,
- the development of new work procedures,
- the development of improved work practices, and
- the optimization of the human resources utilisation.

The main activities which were carried out involved gathering and analysing relevant data, identifying and proposing solutions, implementing and managing innovation, interacting with relevant production operators to make the change happen and evaluating the final results.

Figure 6.22 shows one of the key machinery of the machine shop under investigation as far as the operators' work methods were concerned.

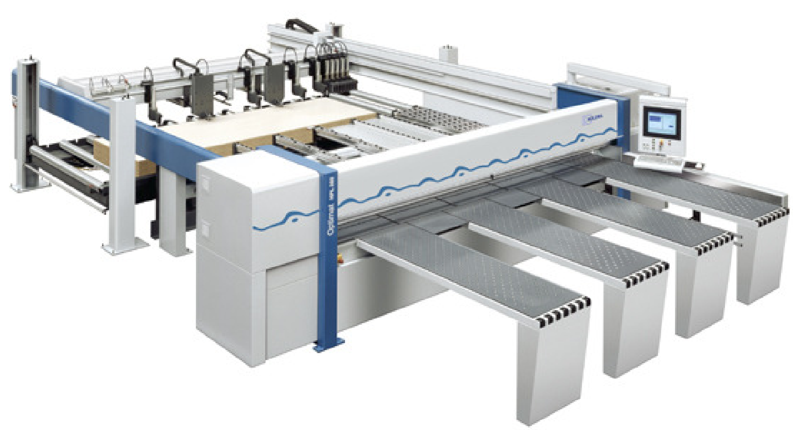


Figure 6.22 – The furniture beam saw (Homag–Holzma HPL380)

6.4.2.1 Data Collection

The first stage of the project was represented by an initial data collection of actual job times for different ranges of products processed through the machinery in the machine shop.
In particular, the data gathered was divided into three main categories:

TIME DATA

- actual job times,
- “touch” times,
- set-up times,
- changeover times,
- maintenance times,
- other unforeseen breakdown times.

The time data were following displayed in spreadsheets highlighting, for each different job carried out, the job time, the operator “touch” time, the set-up and changeover time, etc…

ACTIVITY SAMPLING DATA

The activity sampling data were also displayed in spreadsheets identifying the various activities carried out by the operators working at the beam saws at random times, as figure 6.23 shows.

Date	*Time started*	*Time ended*	*Moving board from the stock to the machine*	*Loading the machine with the board*	*Setting-up the machine*	*Waiting for the board to be cut*	*Moving the cut parts from the machine to a pallet*	*Moving pallets to next department*	*Seeking instructions*	*At stores*	*Elsewhere*
16/04/2007	11:25	11:45									
16/04/2007	14:50	15:05									
17/04/2007	10:30	10:40									
17/04/2007	14:15	14:30									
18/04/2007	13:10	13:30									
18/04/2007	15:40	15:45									
19/04/2007	09:00	09:20									
19/04/2007	12:30	12:35									
20/04/2007	10:30	10:35									
20/04/2007	14:00	14:20									
21/04/2007	11:30	11:40									
21/04/2007	14:15	14:25									
22/04/2007	09:30	09:40									
22/04/2007	13:00	13:20									
23/04/2007	11:50	12:00									
23/04/2007	15:00	15:20									
24/04/2007	10:30	10:40									
24/04/2007	14:10	14:15									
25/04/2007	09:50	10:00									
25/04/2007	13:00	13:15									
26/04/2007	09:00	09:05									
26/04/2007	14:40	15:00									
27/04/2007	10:30	10:40									
27/04/2007	14:30	14:50									

Figure 6.23 – Spreadsheet containing some of the activity sampling data collected

MATERIAL FLOW OBSERVATION DATA

Detailed observation and investigation activities have also been carried out by the researcher within the Machine Shop 1 department which allowed him to better understand the material flow related to the main product lines manufactured by the company.

A thorough data collection process has been completed to this regard by gathering information at the various machines of the department for each job type processed, which allowed the researcher to identify common work paths and sequences throughout the department. The findings of this analysis have been shown in the previous chapters in the figures 6.2 for the factory floor and 6.3 for the machine shop 1 area.

6.4.2.2 Analysis of the Actual Situation

The actual situation was analysed by:

- comparing the actual job times vs. projected job times,
- reviewing the activity sampling data collected at random intervals regarding the different tasks carried out by the operators working on the various jobs, and
- studying the material flow within the machine shop department, in particular from the raw material warehouse to the beam saws and from the beam saws to the CNC machines.

6.4.2.3 Identification of Better Work Methods

The next step of the project involved the identification of better work methodologies through the analysis of the data collected, which was carried out through a team effort involving the researcher, the manufacturing director, the production team leaders and some shop floor operators. In particular, the outcomes of the analysis conducted highlighted the following changes put in place to improve the current work methods:

- different jobs with same material processed together through the machines;
- some spare parts frequently used in different jobs cut in advance;
- some parts for the same jobs processed on the other beam saw when available;
- operators prepared the material for the following job while the machine is still working on the current job;
- operators cut parts in advance during the night shifts;
- new short shifts created so that an operator is replaced with a colleague during breaks;
- new areas identified in to stock the boards ready to be cut and to store the parts just cut;
- board stock in the warehouse arranged more efficiently;
- software of the beam saws enhanced by purchasing a specific module to increase the number of cutting instructions for each job processed (figure 6.24).

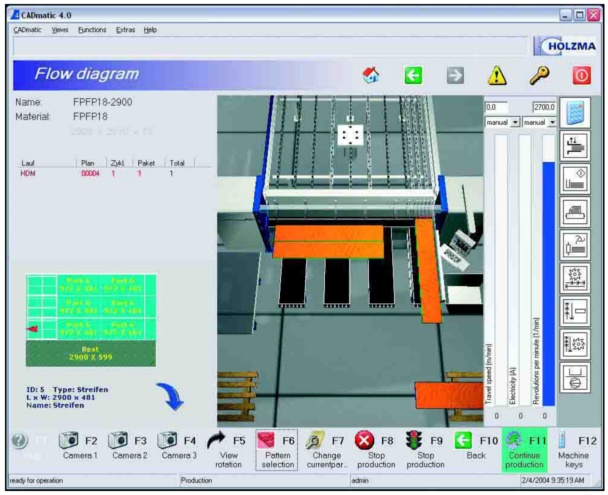


Figure 6.24 – Screenshot of the "Homag-Holzma HPL38" beam saw software

6.4.2.4 Implementation of the Improvements

The following stage of the project was represented by the implementation of the improved work practices. In particular, a data collection after the introduction of the improved work methods was carried out displaying on spreadsheets the information gathered about job cutting times, job set-up times, job changeover times, operator "touch-time", machine overall running time, amount of jobs processed, etc… .

Figure 6.25 shows an example regarding the improvements achieved in terms of job cutting times at the furniture beam saws after the implementation of the enhanced work methods.

WORK ORDER	PRODUCT	Q.TY	CHANGEOVER TIME	TOTAL CUT TIME	
				ESTIMATED	ACTUAL
		pcs	mins	mins	mins
WO 10069	SCOTT SURR	12	15	125	85
WO 10070	TROPEZ	9	10	105	95
PO 7994	SPIRO	12	10	180	145
PO 7995	CITY WENGE	27	20	315	205
WO 10086	HARRIS BATCH A	39	15	300	305
WO 10111	MULL	12	10	130	120
WO 10086	HARRIS BATCH B	21	10	205	195
PO 8019	SPIRO	3	5	50	50
WO 10156	HARMONY	19	5	300	210
PO 8021	CITY WENGE	9	5	125	70
WO 10163	ROMA	4	30	30	25
WO 20879	OMAR	4	10	15	10
PO 8026	OCHIL WALNUT OPERA	6	5	70	50
PO 10173	FARO	3	15	30	35
WO 10197	HARRIS	24	35	160	270
WO 10176	MADDISON	1	5	20	15
WO 10191	HARRIS ROUND	12	20	120	130

Figure 6.25 – Spreadsheet showing the improved job time at the furniture beam saw.

6.5 Machinery Capability Study

Another fundamental task which was carried out by the researcher over a 4-month period was represented by a capability monitoring and analysis performed on some key machinery in the factory. The capability study of some machines in the machine shop became strictly necessary at the beginning of the improvement programme since the production team of the organization realized that the potential manufacturing capacity of some recently bought machines was not completely known. As a consequence of this situation, it was very difficult for the manufacturing management to plan and schedule the production of the job batches as well as for the sale team to agree with the final customers the orders' delivery dates due to inaccurate information regarding some machine capability and, as a result, regarding the product lead time.

6.5.1 Stages of the Implementation

In particular, specific equipments in critical areas of the Machine Shop 1 were selected for this task, focussing the analysis on:

- the two Beam Saws,
- the two CNC Machines,
- the Edge-Bander Machine, and
- the Vacuum Membrane Press.

The main steps of the task implementation are described in the following:

- according to the type of machine under investigation, relevant data and information regarding the large variety of products processed were then recorded on specific forms with the assistance of the departments' operators (e.g. operator skill, inspection methods and equipment, type of raw material used, machine settings, job times, set-up and changeover times, etc…);
- the design processes and the procedures to be considered were then determined by liaising with the Research&Development department;
- the findings of the overall study were then examined on the selected machines along with the manufacturing personnel;
- reports and manuals were then compiled detailing the manufacturing capabilities of the machine based on the data and information gathered;
- the overall outcomes were finally presented to the organization's management;

The machines manufacturing capabilities data gathered, manuals and reports eventually also informed the Failure Mode and Effect Analysis (FMEA) technique implemented at a later stage of the project.

6.5.2 Beam Saws and CNC Machines

A first stage of capability study was carried out in the Machine Shop 1 on the two beam saws and the two CNC machines in terms of machine accuracy when performing the various cutting, boring, round-edging etc… operations. In particular, data of part sizes were collected by measuring samples for various product ranges of furniture and surrounds after being cut and processed at the machines. Then, the accuracy of the machines was assessed comparing the data gathered with the design specifications in relation to the various product ranges and working conditions, e.g. types of material and cutting sequences. The result of this investigation highlighted a high level of accuracy for the recently bought CNC machine and beam saw. The older beam saw and CNC machine, though, proved to be slightly inaccurate. In particular, the average error measured was about 1.5 mm. However, it was agreed with the design team that this did not represent an issue since this value was below the tolerance requested. The furniture and surround departments, in fact, were always able to make up for the machines size errors when assembling the components together since the errors were always below the maximum tolerance value requested. The figure 6.26 shows the recently bought "Weeke" CNC machine, the more modern and accurate of the two CNC Machines used in the Machine Shop 1 department.

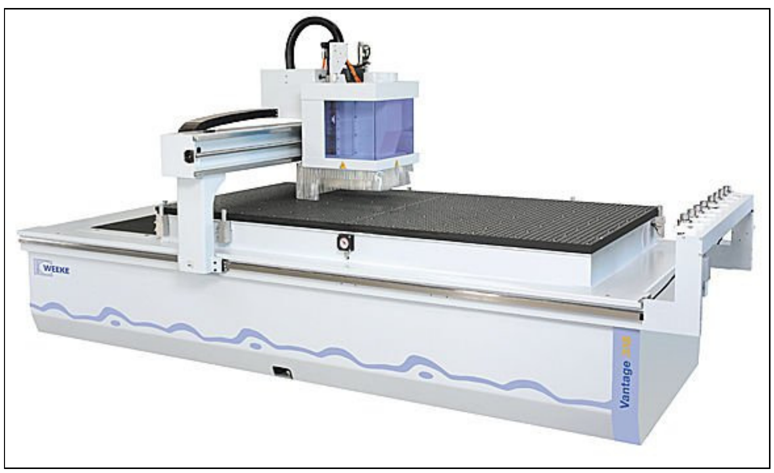


Figure 6.26 – The "Weeke" CNC Machine

6.5.3 Edge-Bander Machine

Then the study moved on to investigate the component processing capability of the "Holzer – Sprint 1317" edge-bander machine used to trim and glue PVC tape on surround, furniture and kitchen components' edges. A first capability analysis was undertaken to assess the accuracy of the machine when trimming edges by measuring samples of parts processed.

The study then focussed on a more critical aspect concerning the production planning tasks, i.e. the evaluation of the machine capacity in terms of time taken by the operators to carry out the various work activities when processing components on the machine (figure 6.27).
The machine control unit stored in the PLC (Programmable Logic Controller) permitted a detailed overview of the operating state of the machine. Network cards and interfaces, automatic operating data acquisition, manufacturing program inputs, and fault reports allowed a straightforward data collection process for the operators and the researcher. The operators recorded on log forms for each job processed on the machine data and parameters which could affect the performance, i.e.:

- tape feed speed,
- tape width,
- tape thickness,
- machine set-up time,
- programme set-up time,
- breakdown time,
- changeover time,
- corner rounding radius,
- glue temperature,
- programme number used.

Some data were gathered through the analysis of the information automatically recorded and stored on the machine PLC by:

- the number of piece counter,
- the amount of edging tape counter, and
- the job time counter.

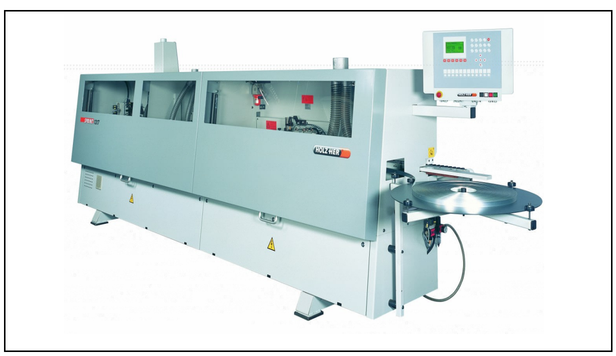


Figure 6.27 – The "Holzer – Sprint 1317" edge bander machine

The figure 6.28 shows an example of some of the data collected by the operators regarding the job orders processed on the machine.

Job No.	Product	Date	Tape Thickness (mm)	Prog	Tape Feed Speed (m/min)	Program Set-up Time	Machine Set-up Time	Breakdown Time	Overall Set-up and Downtime
	ARCTIC	17/12/2007	0.4	3	16	0.5	5.0	0.0	5.5
11442	BORDEAUX	17/12/2007	0.4	3	16	0.5	5.0	0.0	5.5
11448	HOLWELL	18/12/2007	0.4	3	16	0.5	5.0	0.0	5.5
9051	OCHIL H/OAH	18/12/2007	0.4	3	16	0.5	10.0	0.0	10.5
9055	SOUTHBROOK	18/12/2007	0.4		16	0.5	5.0	0.0	5.5
11445	ALICANTE	18/12/2007		3	8	0.5	10.0	0.0	10.5
11450	CHERITON	18/12/2007	0.4		16	0.5	10.0	0.0	10.5
9043	BALLETTA	18/12/2007	0.4		16	0.5	15.0	0.0	15.5
11457	CHATSWORTH	19/12/2007	0.4		16	0.5	5.0	0.0	5.5
	CORDOBA	19/12/2007	0.4	8	16	0.5	5.0	0.0	5.5
	JURA	19/12/2007	2	4	16	0.5	10.0	0.0	10.5
	JURA	19/12/2007	2	5	8	0.5	5.0	0.0	5.5
	total	19/12/2007				1.0	15.0	0.0	16.0
9053	MYSTIQUE	20/12/2007	0.4	3	16	0.5	20.0	0.0	20.5
	KITCHEN	20/12/2007	0.4	3	16	0.5	5.0	0.0	5.5
9078	VIVACE	21/12/2007	0.4	8	16	0.5	5.0	0.0	5.5
9078	VIVACE	21/12/2007	0.4	3	16	0.5	5.0	0.0	5.5
	total	21/12/2007				1.0	10.0	0.0	11.0
9049	CITY + METRO	07/01/2007	0.4	3	16	0.5	5.0	0.0	0.5
9049	CITY + METRO	07/01/2007	2	4	8	0.5	5.0	0.0	0.5
9049	CITY + METRO	07/01/2007	2	5	8	0.5	5.0	0.0	0.5
	total	07/01/2007				1.5	15	0	1.5
11472	KINGSWOOD	07/01/2007	0.4	8	16	0.5	5.0	0.0	5.5
11471	MARBELLA	07/01/2007	0.4	8	8	0.5	5.0	0.0	5.5
11446	ALGARVE	07/01/2007	0.4	3	16	0.5	5.0	0.0	5.5
9064	SPIRIT	07/01/2007	0.4	3	16	0.5	5.0	0.0	5.5
9061	SPIRIT + OCHIL	07/01/2007	0.4		16	0.5	5.0	0.0	5.5
9067	SPIRIT	08/01/2007	0.4	3	16	0.5	5.0	0.0	5.5
9066	JURA	09/01/2007	2	4	16	0.5	5.0	0.0	5.5
9066	JURA	09/01/2007	2	5	8	0.5	5.0	0.0	5.5
	total	09/01/2007				1.0	10.0	0.0	11.0

Job No.	Product	Date	Start Time	End Time	Actual Time	Piece Counter (pcs)	Time Counter (mins)	Tape Counter (m)	Op.	CALCULATED TIME (mins) [TAPE USED / SPEED]	CALCULATED TIME (mins) [(TAPE USED / SPEED) + SET-UP]	TOTAL ACTUAL TIME (mins) [OPERATOR DATA RECORD]	TOTAL ACTUAL TIME (mins) [MACHINE COUNTER]
	ARCTIC	17/12/2007	8.15	8.35	20.0	26	10.0	5.484	2	0.3	5.8	20.0	10.0
11442	BORDEAUX	17/12/2007	12.05			32	15.0	27.100	1	1.7	7.2	0.0	15.0
11448	HOLWELL	18/12/2007	8.25	9.35	70.0	115	46.0	113.684	1	7.1	12.6	70.0	46.0
9051	OCHIL H/OAH	18/12/2007	10.15	12.00	105.0	154	58.0	127.969	1	8.0	18.5	105.0	58.0
9055	SOUTHBROOK	18/12/2007	11.30	13.20	80.0	30	8.0	23.429	1	1.5	7.0	80.0	8.0
11445	ALICANTE	18/12/2007	8.30	14.20	305.0	32	27.0	19.847	2	2.5	13.0	305.0	27.0
11450	CHERITON	18/12/2007	14.20	14.50	30.0	25	11.0	23.665	1	1.5	12.0	30.0	11.0
9043	BALLETTA	18/12/2007	15.00	15.30	25.0	27	11.0	24.577	1	1.5	17.0	25.0	11.0
11457	CHATSWORTH	19/12/2007	8.30			30	11.0	27.657	1	1.7	7.2	0.0	11.0
	CORDOBA	19/12/2007	11.15			28	6.0	27.412	2	1.7	7.2	0.0	6.0
	JURA	19/12/2007	8.00			471	104.0	273.548	2	17.1	27.6	0.0	104.0
	JURA	19/12/2007		12.15		307	83.0	167.865	2	21.0	26.5	0.0	83.0
	total	19/12/2007			240.0	778	187.0	441.413		38.1	54.1	240.0	187.0
9053	MYSTIQUE	20/12/2007	8.30	10.35	110.0	145	66.0	115.682	2	7.2	27.7	110.0	66.0
	KITCHEN	20/12/2007	10.50	16.00	235.0	490	179.0	290.616	2	18.2	23.7	235.0	179.0
9078	VIVACE	21/12/2007				50	31.0	28.363		1.8	7.3	0.0	31.0
9078	VIVACE	21/12/2007				66	29.0	40.798		0.0	0.0	0.0	29.0
	total	21/12/2007			0.0	116	60.0	69.161		1.8	7.3	0.0	60.0
9049	CITY + METRO	07/01/2007	11.45			69	24.0	50.888	2	3.2	3.7	0.0	24.0
9049	CITY + METRO	07/01/2007				172	92.0	104.940	2	13.1	13.6	0.0	92.0
9049	CITY + METRO	07/01/2007				113	65.0	69.744	2	8.7	9.2	0.0	65.0
	total	07/01/2007			270.0	354	181	225.572		25.0	26.5	270.0	181.0
11472	KINGSWOOD	07/01/2007				30	8.0	23.479	2	1.5	7.0	0.0	8.0
11471	MARBELLA	07/01/2007	13.30	13.55	25.0	37	16.0	26.983	2	3.4	8.9	25.0	16.0
11446	ALGARVE	07/01/2007	14.05	14.15	10.0	48	7.0	47.304	2	3.0	8.5	10.0	7.0
9064	SPIRIT	07/01/2007			15.0	26	10.0	23.336	2	1.5	7.0	15.0	10.0
9061	SPIRIT + OCHIL	07/01/2007			20.0	48	16.0	44.280	2	2.8	8.3	20.0	16.0
9067	SPIRIT	08/01/2007			3.0	8	3.0	5.481	2	0.3	5.8	3.0	3.0
9066	JURA	09/01/2007								0.0	5.5	0.0	0.0
9066	JURA	09/01/2007								0.0	5.5	0.0	0.0
	total	09/01/2007			240.0	0	0.0	0.000		0.0	11.0	240.0	0.0

Figure 6.28 – Job order data recorded at the edge-bander machine

6.5.4 Vacuum Membrane Press

The capability study finally focussed on the “Topform - Simimpianti” vacuum membrane press by investigating the aspects concerning the evaluation of the machine capacity in terms of the time taken by the operators to carry out the various work tasks when processing parts on the machine (figure 6.29). The machine was used for 3D application of PVC and similar materials to furniture and kitchen parts and components. The machine was also used to press shaped and curved panels with important radius. This press worked with a rubber membrane by means of bottom vacuum, top pressure and heating system. In particular, the high pressure, the high temperature, and a layer of glue spread by the operators on the components before processing them on the machine ensured the PVC foil to stick to the parts permanently. The machine had a unique system which not only extracted the air from above the foil at the beginning of the process but also at the end of the pre-heat cycle. Air was introduced to separate the foil from the membrane to ensure high quality trouble-free operations with minimum likelihood of creasing. All machine functions were controlled by a PLC unit which was programmed by the operators for different foils or profiles to ensure the result required by the design specifications.

Figure 6.29 – The “Topform - Simimpianti” vacuum membrane press under investigation

During the capability study of the machine, relevant data was gathered for each job processed through a log form by the operators by recording information regarding pressure, temperature, heating time, processing time, type of foil used (sprayed or pre-glued), foil colour, number of beds pressed, number of parts pressed, number of partial defects, number of full defects, type of loading (single or tandem), number of operators, and program number. The information collected for the large variety of products processed on the machine by the operators was then analysed. This study allowed the researcher to gather daily information about number of parts/day, number of beds/day, number of minutes/day, and number of parts/bed. Moreover, the information collected by the vacuum membrane press personnel proved to be fundamental to evaluate the performance of the machine by calculating daily average values of number of minutes/bed and number of minutes/part.

The figure 6.30 shows the data analysis spreadsheet created with the information gathered by the operators on a daily basis. The data collected and analysed were then arranged into tables displaying the data weekly and monthly average values for the same parameters, as figure 6.31 shows. Finally, some of the data monthly average values have eventually been displayed on graphs to represent yearly trends regarding monthly number of parts/bed, number of minutes/bed, and number of minutes/part (figure 6.32).

YEAR	MONTH	WEEK	Day	Parts/Day	Beds/Day	Mins/Day	Parts/Bed	Mins/Bed (Daily)	Mins/Bed (Actual)	Mins/Part (Daily)	Mins/Part (Actual)
2008	MARCH	WEEK 10	Mon 03/03/08	183	27	180	6.8	15.4	6.7	2.3	1.0
			Tue 04/03/08	88	13	210	6.8	32.1	16.2	4.7	2.4
			Wed 05/03/08	89	15	305	5.9	27.8	20.3	4.7	3.4
			Thu 06/03/08	40	10	100	4.0	41.7	10.0	10.4	2.5
			Fri 07/03/08	96	26	320	3.7	16.0	12.3	4.3	3.3
		WEEK 11	Mon 10/03/08	105	16	180	6.6	26.1	11.3	4.0	1.7
			Tue 11/03/08	415	45	350	9.2	9.3	7.8	1.0	0.8
			Wed 12/03/08	275	41	345	6.7	10.2	8.4	1.5	1.3
			Thu 13/03/08	212	35	300	6.1	11.9	8.6	2.0	1.4
			Fri 14/03/08	179	34	320	5.3	12.3	9.4	2.3	1.8
			Sat 15/03/08	70	10	150	7.0	41.7	15.0	6.0	2.1
			Sun 16/03/08	137	18	270	7.6	23.2	15.0	3.0	2.0
		WEEK 12	Mon 17/03/08	168	23	310	7.3	18.1	13.5	2.5	1.8
			Tue 18/03/08	330	50	425	6.6	8.3	8.5	1.3	1.3
			Wed 19/03/08	175	32	365	5.5	13.0	11.4	2.4	2.1
			Thu 20/03/08	187	32	360	5.8	13.0	11.3	2.2	1.9
			Fri 21/03/08	114	26	310	4.4	16.0	11.9	3.7	2.7
		WEEK 13	Tue 25/03/08	180	26	370	6.9	16.0	14.2	2.3	2.1
			Wed 26/03/08	178	21	195	8.5	19.9	9.3	2.3	1.1
			Thu 27/03/08	236	30	340	7.9	13.9	11.3	1.8	1.4
			Fri 29/03/08	184	23	225	8.0	18.1	9.8	2.3	1.2
			Sat 29/03/08	50	5	60	10.0	83.4	12.0	8.3	1.2
			Sun 30/03/08	121	12	120	10.1	34.8	10.0	3.4	1.0
MONTHLY AVERAGE		2007	NOVEMBER	147	18	283	8	24	16	4	2
			DECEMBER	166	24	290	7	24	15	4	3
		2008	JANUARY	155	21	234	8	49	12	9	2
			FEBRUARY	166	21	222	7	21	11	3	1
			MARCH	166	25	286	7	23	11	3	2
OVERALL AVERAGE (LIVE)				164	23	282	7	29	13	4	2

Figure 6.30 – Data analysis spreadsheet created with the data recorded daily

WEEKLY								
TOTALS			AVERAGE					
Part	Bed	Min	Parts/D	Beds/D	Mins/D	Parts/B	Mins/B	Mins/P
WEEK 23:								
141	192	169	353.3	48.0	422.5	8.8	11.2	1.7

		MONTHLY AVERAGE					
		Parts	Beds	Mins	Parts/Bed	Mins/Bed	Mins/Part
NOV '07		147.2	18.2	282.8	7.6	16.5	2.4
DEC '07		165.9	23.6	289.6	6.8	14.8	2.6
JAN '08		154.9	20.8	233.9	7.6	12.5	2.2
FEB '08		165.7	20.7	222.1	7.2	11.2	1.5
MAR '08		171.9	27.6	284.3	6.3	11.2	1.9
APR '08		208.4	30.6	312.3	6.9	10.7	1.8
MAY '08		203.8	30.0	321.5	7.1	12.3	1.9
JUN '08		235.4	37.0	317.6	6.7	9.8	1.5
JUL '08		87.6	12.3	185.0	6.8	15.2	2.5
AUG 08 (LIVE)		123.5	20.0	256.3	6.0	12.8	2.1

Figure 6.31 – Data weekly and monthly average values

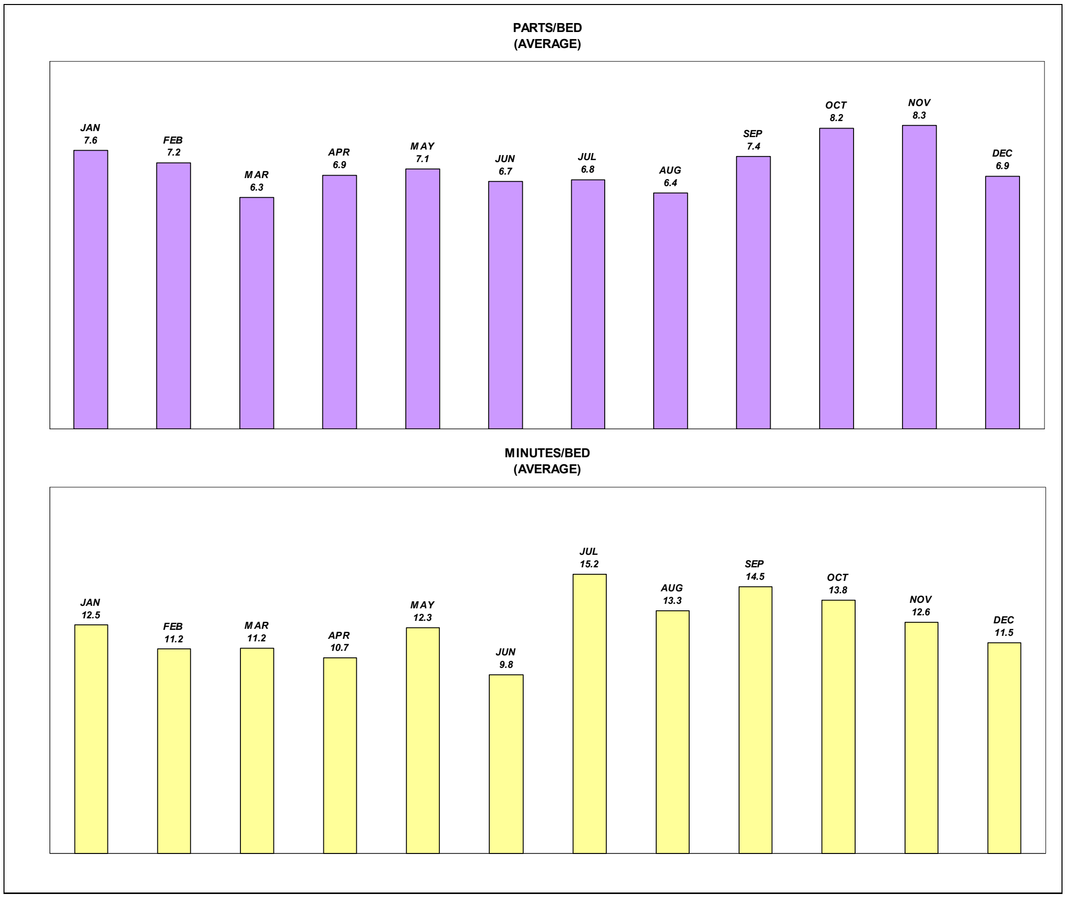


Figure 6.32 – Examples of graphs displaying some of the membrane vacuum press monthly average data (parts/bed and minutes/bed)

The figure 6.33 shows a snapshot of the software "Line-Control" which, as it will be described in one of the following chapters, was eventually installed into the machine and used along with a scan device system to supervise the whole pressing process.

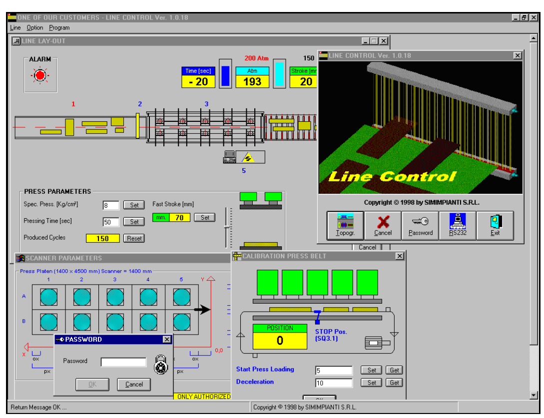


Figure 6.33 - Page of the "Line-Control" software used with the "Scan-Control" hardware

6.6 Value Stream Mapping and Computer Simulation of the Manufacturing Processes

One of the most important tasks carried out during the overall improvement programme was represented by the value stream mapping and subsequent software simulation of the manufacturing processes in place within the company.
This task became necessary towards the end of the programme due to a critical requirement of the furniture market whose customer demand was moving towards a scenario characterized by more and more flexibility and variety required in terms of:

- smaller job batches,
- more customised products, and
- a faster customer response time.

This new situation of the market was likely to cause further unwanted capacity constraints to the organization's production machines and departments, which were already utilised almost at full capacity with recurrent bottlenecks, as the following chapter highlights.

6.6.1 Actual Situation at the Company

The issues the company was facing were due to the variety of products they offered combined with the relatively short delivery time target, which caused bottlenecks to the manufacturing line reducing the overall productivity. The company was not able to predict when, or at which machine the bottlenecks would have occurred at. They were occurring at various machines, and the cause mainly depended on the production schedule. The bottlenecks could not easily be predicted, as the production schedule could not identify what machines each product would have been at and when it would have been there. When the bottlenecks occurred, there were many side effects like not being able to continue manufacturing products at the required rate. While machine stations had bottlenecks, the whole production line slowed down, resulting in loss of productivity. Sometimes the staff members at other stations were left idle, since jobs could not be processed or they had no work to process. This meant that they were inefficient and costing the company money without providing any output. Another problem which was affecting production and which was a result of the frequent bottlenecks was represented by the large increase in product manufacturing lead times. Often these increased lead times could cause time delays, which affected the order delivery time. The company sometimes ended up with lost business or a poorer reputation as a result of failing to make there target delivery date. At that moment the company was only able to deal with these problems as they were arising – therefore reactively and not proactively - and could not forecast them in advance in order to prevent the issues from occurring. One of the main root causes of this situation was represented by the fact that they were working on a reactionary basis, instead of a much more efficient pro-active system, which would have allowed forecasting the customer demand as well as possible solutions to cope with potential capacity constraints at the machines or in the departments, for example when the demand was high for one specific product or when the product mix would have likely caused a bottleneck at a particular work centre. The organization, however, put in place some countermeasures in order to handle the situation. Fir instance, at the beginning of a working week, experience had allowed the company to try to prevent potential bottlenecks with methods such as splitting the batch order. This meant, for example, that they could process most of a batch if this was particularly large. However this was not efficient since the machines then needed to be set up twice in order to complete one only batch. This again caused problems with delivery times, as sometimes large orders were being shipped to one company, which would have expected the whole order to be delivered together and on time. It was became apparent then to the company that this was not the right way forward and a different proactive approach needed to be investigated.

6.6.2 Purpose of the Task

It appeared then clear that it was necessary to carry out a software simulation with the aim of evaluating and tackling in advance the areas where potential capacity constraints could have occurred in a predicted future scenario characterised by the mentioned new customer demand features. The purpose of this task was then to develop a model useful for the company to determine where bottlenecks might have occurred in the manufacturing line once weekly orders had been forecasted. The ultimate aim of this task was to allow the organization to review their current facility and look at the final recommendations made based on the simulation results generated. These recommendations intended to solve various issues occurring in production, as explained, and provide a smooth flowing facility which aimed at improving the overall competitiveness of the company.

6.6.3 Stages of the Implementation

The simulation of the manufacturing processes of the organization was performed following three main stages, each of them characterised by several sub-activities. They are described as follows:

STAGE 1: Analysis of the current state value streams, planning data, bills of material, routings, product ranges, product demand patterns, and product mixes

- development of process maps of value streams for each main manufacturing area;
- creation of a dataset of operation times for each main manufacturing area;
- creation of routings and bills of material for each product line;

- measure of the variation in capacity utilisation for the critical activities;
- identification of operations causing capacity constraints in the current market scenario;
- "Simul8" software training course undertaken by the researcher at the University of Strathclyde.

The findings of this first stage highlighted that the high variety and small batch size product mixes processed in the factory created bottlenecks at some production work centres and increased lead times, as also confirmed by the lead time data collected over a period of some months.

STAGE 2: Simulation of the manufacturing processes for the actual job order mixes over a 3-week period

- model reflecting the manufacturing processes for typical product ranges built through the software "Simul8" to test the validity of the operations data (machines/departments capability in terms of minutes available);
- job order mix routings and capacity requirements in terms of minutes loaded into the software through a "job matrix" created through an "Excel" spreadsheet;
- simulation of the current value streams for the existing product ranges run over a 3-week period;
- results of the simulation analysed in terms of lead time, inventory, queues data;
- operations data (machines and departments capability in terms of minutes available) tested, verified and validated through:
  - new production planning and control spreadsheet "P10" (for estimated bottlenecks and extra capacity required);
  - actual against simulated lead time data comparison;
  - visual work-in-progress and queues checks in the shop floor departments.

After some adjustments and fine tuning, the model proved to be reliable in simulating the manufacturing processes since it provided accurate inventory, queue and lead time data which matched the actual values recorded in the shop floor.

Different scenarios have been simulated and the results averaged for the same order mix over a 3-week period of time taking into consideration an increased capacity in various departments and machines:

- increased number of operators in the Cabinet Shop/Furniture/Kitchen Assembly;
- increased number of operators in the polishing shop;
- increased number of beds processed at the same time at the vacuum membrane press;
- increased number of CNC machines working simultaneously in the machine shop

STAGE 3: Simulation of the manufacturing processes for future predicted customer demand patterns

- generation of future value stream patterns for various anticipated product mixes;
- machine capacity and manning requirements identified through further simulation runs;
- analysis of current against future machine and manning capacity requirements predicted;
- identification of manufacturing areas where machine and manning capacity needs to be increased;
- analysis of the overall findings;
- presentation to the board of directors of an improved scenario with recommendations for methods to increase the capacity in specific production areas.

The following chapters highlight more in detail some of the critical activities carried out during these three main implementation stages performed to complete this task.

6.6.4 Stage 1: Analysis of the Current State Value Streams

6.6.4.1 Process Mapping

In order to carry out a software simulation, it was first necessary to perform a value stream mapping of the actual production activities in place in the factory.
The outcome of this activity represented then the input for the creation of a graphical model with the software "Simul8" to carry out the computer simulation.
The manufacturing areas of the company needed to be defined by using process mapping techniques to reveal the value adding activities carried out for the typical product ranges. The researcher carried out this task by "following" the products as they were planned and manufactured and by identifying the documentation and materials used at each stage. In particular, the information collected at each machine and department included data such as:

- bills of material, product routings, processing lead time, "takt" time, touch time, cycle time, set-up time, changeover time, idle time, "availability" time, total work time, amount of work-in-progress, resources required per operation, and machines involved in process.

The outcome of this activity was represented by the documentation of the process maps for each product group. Figure 6.34 shows one of the actual "work sheets" used to document the internal door process value streams.

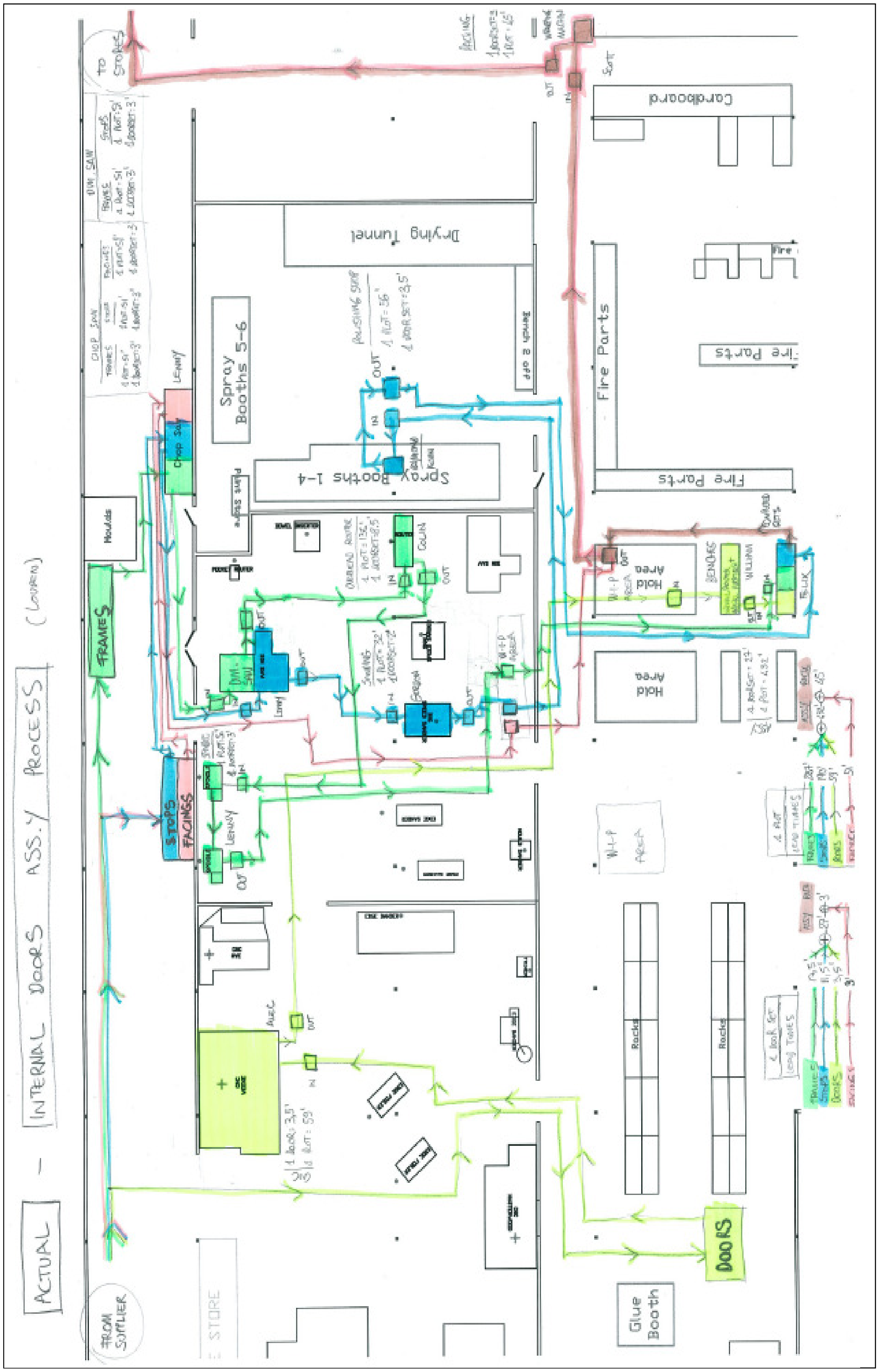


Figure 6.34 –One of the actual "work sheets" used to map the internal door process

Once the process mapping revealed and documented the main activities, the duration of these operations for typical product types has been measured by the researcher by observation as orders were being progressed. This study, along with a thorough analysis of the job times data (allocated and actual) gathered for each department/machine, allowed to create a dataset of operation times for each manufacturing area. The data gathered during the process mapping task have then been used by the researcher to create routings and bills of material (BOM) for each of the product ranges investigated. The variation in capacity utilisation for the critical manufacturing activities has also been measured in order to monitor the capacity variation for the current product mixes and demand profiles. This allowed the researcher to identify operations causing capacity constraints in the actual manufacturing scenario and analyse the reasons they occurred for specific job orders.

6.6.4.2 The Computer Simulation Software

As mentioned beforehand, the data gathered through the value stream mapping activity characterised the input for the development - with the software "Simul8 ®" - of a graphical model to perform the computer simulation of the current and predicted manufacturing scenarios. The software simulation of the production processes represented a key tool in observing, understanding and analysing the effects of the job order mixes on the manufacturing operations. Computer simulation is a tool to understand how a company operates, and how to improve the decision making process. The software provided a facility that to be set-up required very detailed information about the procedures involved within the manufacturing processes. The software was a graphical programme which used five entities to display different functions, and could easily be controlled in order to represent these functions with respect to the shop floor. The types of entities available were entry points, storage areas, work centres, resources and work exit points. Once the model was built to reflect the manufacturing processes in place within the company, features such as resource allocation in terms or number of operators or shifts could be changed and adjusted to accurately represent the shop floor characteristics. The model used has made some assumptions which facilitated the simulation task but did not highly affect the final results validity. Occasionally, some product parts from the same work order did not go through the same work centres and followed different routes from the other parts. For these products, an average route has been derived and taken into account when building the model. Although this meant that sometimes the model did not show the true nature of the manufacturing process, the deviation was small and did not affect the final results.

6.6.5 Stage 2: Simulation of the Manufacturing Processes in the Current Situation

6.6.5.1 Building Up the Simulation Model

In order to set up the simulation model with the correct information, the researcher analysed the manufacturing processes in place and their interactions in real life. Information such as machine locations as well as where raw materials were delivered and stored in the factory was also retrieved. Fundamental to this purpose was the value stream mapping information collected at a previous stage of the task regarding the machine capability and processing times (e.g. set-up times, changeover times, average maintenance intervals and duration, average breakdown frequency and duration, etc…). In particular, for the various product ranges the following information was retrieved and analysed:

- material delivery schedule and locations, product bills of material, product routings, actual production processes and activities carried out at each stage, actual manufacturing times at each work centre.

First, the researcher had to gain a clear understanding of the machines and resources which were required to operate them. For this purpose it was important to understand how the factory worked, who the operators involved were and the different routings the various products followed. Gaining an understanding of the shop floor was achieved by analysing manufacturing procedures data and paperwork as well as by thoroughly observing how the various products were manufactured and how the different production areas worked within the process. Once the working procedure observation and analysis stages had been completed, it was possible to graphically create the simulation model by using the software “Simul8” to reflect the actual factory floor layout and production processes. One of the main goals in building up the model was to make sure that it properly represented in detail the actual work centres and work activities carried out on the factory floor, mainly the material flows and the production scheduling.

6.6.5.1.1 The “Job Matrix” Feature

In order to schedule when jobs had to be processed, what routing they had to take through the factory and how long they had to spend at each work centre, it was necessary to use an important control tool provided by the software: the job matrix.

This represented a fundamental tool in the simulation activity which required accurate information regarding the work centre sequence, the setup/changeover times, and the time spent at each machine by each job order type during the manufacturing process.

The job matrix function allowed many different job batches to pass through the factory simulation model taking various routes reflecting what was actually happening on the factory floor. The matrix worked according to a label system. A label was assigned to each job order entry point, called “work item”. This label represented a constant value which remained the same and stayed with the work item throughout the manufacturing process. The work item had another label assigned called “job” label, which was incremental, and it was used to tell the work item where to go throughout the factory reflecting the real routing in the actual production process. The matrix used both these labels to control each job order item in the manufacturing process through the factory. The number of batches produced for each product type each week was usually quite small, which made the weekly product mix vary a lot. For each different product type, a new machine sequence and processing times had to be allocated, as well as “job” and “work item” label values. Then the data had to be added up to reflect the batch quantity. Once the batches of job orders were “loaded” into the software and the simulation run was started for a particular period of time, the work items “entered” the system and the matrix controlled the movement of the job order batches and processed them through the model built from the beginning of the manufacturing process – the cutting at the beam saws - all the way to the end – the packing and storing into the warehouse. Figure 6.35 shows a sample of the job matrix and the data stored within the matrix. The times for each machine in the job matrix are dependant on the product type.

CUT DATE	SHEET	JOB	QTY	WT	J	LOCATION	TIMING
Monday 26/05/2008	K10	POR2205	2	1	1	Grey Beam Saw	4
				1	2	'Weeke' CNC Machine	8
				1	3	Membrane Press	15
				1	4	Packing	10
	S10	WO11710	15	2	1	Green Beam Saw	90
				2	2	'Weeke' CNC Machine	120
				2	3	Spindle	150
				2	4	Dim Saw	45
				2	5	Pocket Router	75
				2	6	Mould Sand	90
				2	7	Edge Sand	75
				2	8	Face Sand	75
				2	9	Cabinet Shop	450
				2	10	Polishing	470
				2	11	Fitting and Final Inspection	75
				2	12	Packing	150
		PO9795	3	3	1	Green Beam Saw	21
				3	2	'Weeke' CNC Machine	9
				3	3	Edge Bander	7
				3	4	Dim Saw	12
				3	5	Pocket Router	12
				3	6	Cabinet Shop	105
				3	7	Polishing	211
				3	8	Packing	38
		WO11711	12	4	1	Green Beam Saw	100
				4	2	'Weeke' CNC Machine	70
				4	3	Edge Bander	24
				4	4	Spindle	96
				4	5	Dim Saw	24
				4	6	Pocket Router	60
				4	7	Mould Sand	48
				4	8	Edge Sand	24
				4	9	Face Sand	12
				4	10	Cabinet Shop	288
				4	11	Polishing	392
				4	12	Fitting and Final Inspection	168
				4	13	Packing	144

Figure 6.35 – Job matrix sample used to “load” onto the software the job orders

6.6.5.2 Simulation of the Current Scenario and Validation of the Model

Once proficient in the use of the manufacturing process simulation software “Simul8”, the researcher was ready to carry out some computer simulations of the current state value streams for the product ranges manufactured by the company. The data generated in the previous stages have been used to build the simulation model for typical products in order to test the validity of the operations data before using the model created to simulate the future cellular value streams. Once the model had been set-up and loaded then, it was ready to simulate the production processes for a particular job orders mix over a specific period of time which was agreed to be three weeks for the simulation of an anticipated customer demand scenario. At this point some initial simulation runs of real weekly job order mixes on the go in the shop floor were carried out over a period of some weeks in order to validate the information used to create and set-up the model. This was done by observing the model results in real time during the simulation and verifying that at any time the job processing times, production lead times, queues and work-in-progress data of the job order batches loaded into the software reflected those that were actually occurring in the factory floor. The work order mix was constructed using data from the weekly production planning spreadsheets and it allowed to simulate and verify in real time the movements of the job batches on the factory floor. The data used for the validation runs represented an actual production order mix reflecting the customer demand that the company was experiencing at that time: this was crucial in order to verify in real time the model created. The table in Figure 6.36 illustrates the results obtained at the end of a simulation run for some work orders processed. For each job order, the data gathered are related to the batch quantity, the number of processes the batches went through, the overall time spent in the work centre queues during the overall manufacturing process (wait time), the total processing time or touch time (work time), and the overall production lead-time.

WORK ORDER	QUANTITY	CUT WEEK 21 - 22 - 23				
		PROCESSES	WAIT TIME	WORK TIME	S8 LEAD TIME	
			Minutes	Minutes	Minutes	Working Days
1 WO11700_30	30	13	71	6669	6740	7.0
2 CIWPO9778_4	4	6	3063	35	3098	3.2
3 PABE PO9779_11	11	5	5578	429	6007	6.3
4 HR PO9780_5	5	9	8227	639	8866	9.2
5 HR PO9780A_2	2	10	8759	113	8872	9.2
6 FV PO9781_5	5	10	8300	1332	9631	10.0
7 POD91984_20	20	7	2501	564	3066	3.2
8 PO25341_362	362	6	598	2677	3275	3.4
9 WO11704_12	12	5	6854	64	6918	7.2
10 WO11705_3	3	14	1815	1516	3331	3.5
11 WO11706_3	3	13	2469	874	3343	3.5
12 PO9747_12	12	13	2525	830	3355	3.5

Figure 6.36 – Example of some of the data obtained after a simulation run

After some required adjustments, the model proved to be realistic and accurate in replicating with precision the production processes of the company since it provided the researcher with data which matched the actual situation on the factory floor. The analysis of the results obtained after the simulation run were consistent with the problems that the company was facing. The model was then proved accurate and reliable and it was ready to be used to simulate a future manufacturing situation, to identify possible solutions to the problems, and to test these solutions to determine which were most effective in order to help eliminate bottlenecks and, ultimately, to reduce production work-in-progress and lead times.

The company, then, was provided with an accurate model which could have been used to simulate future anticipated demand profiles and product mixes in order to investigate the effects on lead times and throughput and to make changes on time to cope with potential machine and manpower capacity constraints.

6.6.6 Stage 3: Simulation of the Manufacturing Processes in the Anticipated Future Scenario

The researcher, therefore, moved on to the following step of the task by using the simulation model to generate and simulate value streams for anticipated demand profiles and product mixes using 75% capacity utilisation at critical operations for each manufacturing area. The simulation model has been then used to identify resources such as machine capacity and manning requirements for the anticipated demand profiles and product mixes for each product range and manufacturing area under investigation. In order to simulate an anticipated customer demand scenario in the future market situation, various three-week product mixes that the company could expect in the future months were identified with the assistance of the sales personnel and loaded into the model created by using the job matrix feature. The mixes identified were constituted by a high number of small batch quantities of many different new and standard products characterised by:

- an increase of the amounts of various furniture ranges but in smaller job batches,
- a significant amount of internal door units, and
- a decrease of the number of surround batches,

as this was anticipated to be the future market demand. The job matrix, in this case, was characterised by 86 work orders displayed in 1328 rows, each one corresponding to a work centre. Using a three-week period allowed the researcher to develop a potentially real situation by simulating aspects such as inventory, queues and breakdowns during the overall production process. Once the model was set up, several simulations with the different product mixes identified were carried out to determine the average performance of the system over the three-week period of time. The simulation runs of the future scenario provided a graphical representation of the potential issues which could have occurred in production in the new expected situation of the market. Figure 6.37 shows a model snapshot of the machine shop 1 and 2 areas during one of the simulation runs – it is possible to appreciate some long queues representing high volumes of product work-in-progress and backlog.

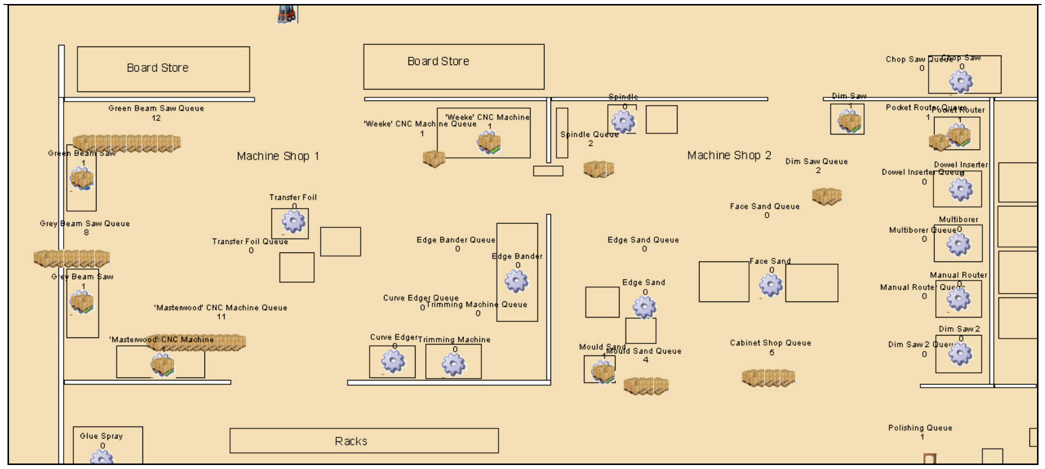


Figure 6.37 – Snapshot of the model of the machine shop areas during a simulation run

6.6.6.1 Results of the Simulation Runs in the Anticipated Future Scenario and Possible Solutions to the Issues Identified

Using the information generated during the simulation of the manufacturing processes in the expected customer demand scenario, the researcher identified the areas where extra capacity in terms of manning requirements was needed. The simulation runs showed that some of the machines were used over capacity, while others were working under capacity or not working at all. This was mainly due to the manufacturing processes for some of the product ranges being very similar. This meant that an increase in the process of manufacturing specific product ranges would have caused larger capacity constraints and longer production lead-times than a similar increase in the production of other specific ranges according to the different manufacturing process routings. For instance, an increase in the batch quantity obviously meant that the items were taking longer to reach stages further down the production process, since usually a batch moved to the next production step only once all the items included in it had been fully processed at a work centre. Some of the changes needed, therefore, regarded increasing the capacity levels on the processes involved in manufacturing the products which were more likely to be requested by the customers in the future market scenario. Figure 6.38 shows an example of some of the data gathered at the end of a simulation run in the dispatch department.

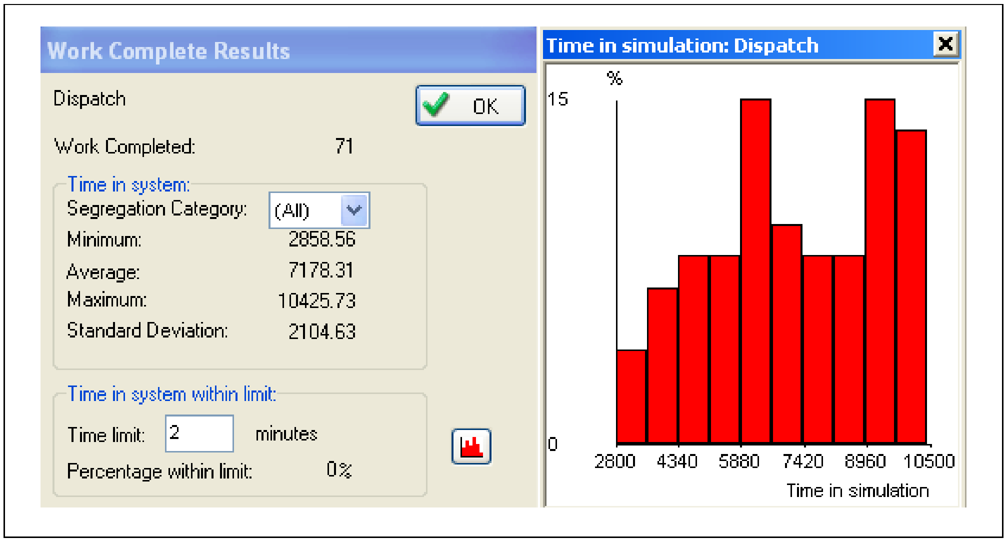


Figure 6.38 – Example of some of the results obtained in the dispatch department after a simulation run

In the simulated future manufacturing scenario, many of the capacity constraints occurred in the machine shop 1 area at the “Weeke” CNC machine, due to the particular product mix identified as representative of a possible typical future client demand. The machine was already utilised over capacity in the current customer demand situation and was already experiencing recurrent bottlenecks. This meant that the bottlenecks at this machine would have been greatly increased in the future. The company had two CNC machines within the machine shop 1 area, however only the “Weeke” CNC machine was able to cope with the complex work needed to process both the fire surround and the internal door units. This machine was also much quicker and tended to be preferred to the older and more basic “Masterwood” CNC machine for those kinds of job orders. During the simulation run, many of the problems occurred at this early stage with bottlenecks at the “Weeke” CNC machine constituted by internal door and fire surround units prevented from being processed and released. Doubling the capacity of the “Weeke” CNC machine would have definitely helped to reduce the queues and to decrease the processing lead-times at this work centre. Since a capital expenditure to purchase another CNC machine was out of the equation due to the high cost involved and to the uncertainty of the future market demand, this was achievable by creating an extra shift (backshift or nightshift) when needed.

Moreover, a forecasted increase in the furniture orders - which was reflected in the product mix chosen for the simulation runs - caused capacity issues in specific machines used in this manufacturing process since many resources were not available to be used to process the other product ranges of the anticipated product mix. However, as the process was much less congested, the bottlenecks of work items tended to build up at the furniture assembly stage, as this activity required a much longer processing time. A possible solution to this issue was achievable by using the fire surround assembly department operators as well to build the furniture units since the surround demand was anticipated to decrease in the future customer demand. This would have allowed to increase the manning capacity by sending the furniture units to both the assembly points, so that they could have been assembled at whichever work station was free, whether it was the furniture or the fire surround assembly department.

Large queues were also occurring at the two “chop saws” in the storage and machine shop 2 areas when the internal door frames were processed. The reason for such large queues was that the material supplied to the company was in large - five metre strips. In fact, in order to bring the material from the storage area into the factory, it all needed to be cut down to a 3-metre size at the chop saw in the storage area. Then once in the factory, the material needed to be cut again accurately to the size required by the design specifications at the second chop saw in the machine shop 2 area. These work activities were all very time consuming. Increasing the capacity of the two work centres at this point would have made a little difference, as all the work centres involved in the internal door manufacturing process were already experiencing capacity issues and the bottlenecks would have then moved with the material to one of the next steps of the process. Much of the early work activities of the internal door manufacturing process, in fact, were short and easy to complete if capacity constraints were not occurring: this situation tended to push products through the production line too quickly for the more intricate work to be carried out later on. The overall manufacturing process was working well until the internal door units entered into the system creating lengthy bottlenecks at various work centres. Only increasing the capacity at all stages of the internal door production would have efficiently streamlined the all process.

The simulation runs also indicated that, even if the amount of fire surround units forecasted in the future market scenario decreased, the number of operators in the fire surround assembly department (cabinet shop) to cope with it was still not enough and, depending on the overall job order mix processed, some queues were occasionally still occurring, as they were in the current manufacturing situation. There were only very few operators properly trained to carry out the fire surround assembly activity and this highlighted the need to train some extra personnel to employ in the cabinet shop department when required according to the queue and backlog situation.

The simulation highlighted also other issues due to some machines in the machine shop 1 and 2 areas not being used even if the job batches were ready to be processed. This was caused by the lack of specific training for several operators in the shop floor.

For instance, the simulation run highlighted that this problem occurred very often at the “dimensional saw” when the product mix included internal door and surround units and when they arrived at the work centre at the same time since they both had long processing time at that machine. The machine shop 2 area had two “dimensional saws” available, however they were both very rarely used at the same time which made one machine redundant since there were not enough operators trained to use them. During the simulation run, the model accounted for this by using resources accordingly to operate the machines by only sending resources in terms of operators to the machines when they were available which was very rarely as they were often using other machines to process other job batches.

6.6.6.2 Identification and Implementation of the Solutions in New Simulation Runs in the Anticipated Future Scenario

Once completed the analysis of the outcomes of the simulation run in the anticipated future scenario, it was then possible to alter various aspects of the model in terms of production capacity and, by running other simulation runs, to verify the average outcomes of the changes in order to try to resolve in theory the problems occurred during the simulation before applying the solutions into the real manufacturing environment of the factory floor. A new changed production model with increased machinery and manning capability at the critical manufacturing areas needed to be created and simulated again for the same anticipated demand profiles and over the same period of time in order to verify the outcomes of the changes identified and to make sure that further bottlenecks were not occurring in any other production area of the shop floor. The researcher, thus, undertook an analysis of the current against the future machines/equipment and manning requirements predicted by the results of the simulation runs and occurring when producing according to the new customer demand in the changed market scenario - small batches, more customised products, shorter manufacturing lead-time. It was then possible to determine the optimum machine capacity and manning requirements for the future anticipated product value streams. For that reason, once the results of the simulation runs had been averaged, reviewed and analysed, possible and realistic changes have been identified, discussed and agreed with the production team. These changes have then been applied to the model to help solve some of the capacity issues identified and to increase the work flow through the factory with the ultimate aim of reducing the average inventory at the various work centres and decreasing the overall manufacturing lead time. To this purpose, the following changes were made to the simulation model in an attempt to help reduce the various bottlenecks and areas that were slowing production and increasing the lead times:

- Due to the large number of products processed at the “Weeke” CNC machine, a backshift was introduced into the model in order to reduce the large queues at this work centre. It was not possible to introduce a second “high-performance” CNC machine “in parallel” with the “Weeke” CNC machine into the model since the company at that time could not afford the capital expenditure necessary to purchase any expensive extra machinery.
- During the simulation runs, long queues were forming at the assembly point for furniture units, while occasionally the cabinet shop (fire surround assembly) had little work to process. The model was then changed in order to combine these two work centres and,

after the proper cross-training, share the resources when needed to help reduce the overall queues. Resources in terms of operators from the cabinet shop were therefore made available to the furniture assembly point when there was no work at the cabinet shop.

- During the simulation runs, work could not be sent to the two “dimensional saws” at a proper rate to keep the manufacturing flow moving fast enough due to the lack of resources available to operate both the machines. A resource in terms of an extra operator properly trained was therefore added and made available from the machine shop 2 department to operate the machines when not busy working on other tasks.
- An extra operator from the machine shop 1 department was also properly trained and made available when required to the cabinet shop since occasionally queues were forming at that work centre due to the lack of operators with enough experience to assemble fire surround units.
- Finally, in order to streamline the overall internal door manufacturing process which, as said, was negatively affecting the production process of several other product ranges, some extra operators from other various departments were properly trained in specific operations and made available to increase the manning capacity of the work centres involved. This was possible to achieve since the internal door assembly process was highly relying on manual activities and skills and did not require the purchase of any extra machinery or equipment.

Implementing the identified changes into the model provided fundamental feedback on how these changes improved the situation at specific work centres and how they affected the overall manufacturing process before applying them into practice. The new simulation runs were carried out over the same three-week period of time by loading into the software the same job order mix used for the initial runs. It was therefore possible to evaluate the results achieved in theory and then put the changes in place into the real manufacturing processes.

The results obtained through the initial runs were then compared against the outcomes of the new runs carried out in the predicted future scenario through the modified simulation model with the aim of analysing how the changes affected the manufacturing processes.

Figure 6.39 shows the comparison between the lead-time data of some job batches at the end of two simulation runs representing two different production situations: 1 CNC machine for the current situation and 2 CNC machines for the future situation. It is possible to appreciate the significant decrease of the lead-time data values in the manufacturing scenario with 2 CNC machines running “in parallel” for almost all the job orders processed - the green cells in the table represent shorter lead-time values, whereas the orange cells represent longer lead-time values for the same job order in the two different production simulation scenarios.

	1 CNC Machine			2 CNC Machines		
Work Type	SEQ.	Lead Time (days)	WEEK	SEQ.	Lead Time (days)	WEEK
3	1	9.2	22	1	6.4	22
4	-	Not compl.	Not compl.	2	7.4	22
5	-	Not compl.	Not compl.	3	7.1	22
6	-	Not compl.	Not compl.	4	6.4	22
7	2	3.2	21	5	2.4	21
10	3	5.3	22	6	4.4	22
11	4	5.4	22	7	5.4	22
12	5	7.2	22	8	5.4	22
13	-	Not compl.	Not compl.	9	6.2	22
14	-	Not compl.	Not compl.	10	7.4	22
15	-	Not compl.	Not compl.	11	7.2	22
18	6	6.1	22	12	4.8	22
20	7	8.1	22	13	8.3	22
21	8	8.2	22	-	Not compl.	Not compl.
35	9	8.4	22	14	6.1	22
41	10	5.2	22	15	5.2	22
41	11	5.2	22	16	5.2	22
51	12	7.2	22	17	5.8	22
52	13	7.2	22	18	5.5	22
53	14	7.4	22	19	7.7	22
65	-	Not compl.	Not compl.	20	9.2	22

Figure 6.39 – Comparison between the lead-time results of two simulation runs representing two different production scenarios with 1 and 2 CNC machines

The results of this analysis and the benefits the company accomplished by performing this task are described in chapter 7.

6.6.6.3 Final Recommendations on Specific Methods to Cope with Capacity Constraints Identified in the Anticipated Future Scenario

The final simulation runs carried out taking into consideration the anticipated future customer demand highlighted some critical aspects which were emphasized to the organization management:

- Need to increase the capacity of the CNC operations by purchasing another "high-performance" CNC machine with enhanced processing capabilities to be used "in parallel" to the "Weeke" CNC machine. Investment in this type of machine would benefit the company since it is critical to the manufacture many of the product ranges produced.

- Having properly cross-trained personnel and moving it around to various machines and departments to cope with increased product loads would help using all the machines available at all times, therefore reducing bottlenecks and keeping the staff working instead of waiting for work. A cross-training programme would also allow the company to invest in new machines and equipments without having to hire new personnel to operate them as the existing work force could be able to handle a machinery increase.

- Need to dedicate a specific production line to the internal door process if the product sales should further increase. This would release resources in terms of operators and machinery/equipment to concentrate the other product ranges requiring the same resources.
- If the product mix loaded at the beginning of the manufacturing chain is characterised by a large amount of units, there must also be a look at processes further down the production line in order to make sure that the bottlenecks does not simply move down the factory to different critical areas. Having an overview to the whole production process and tackling in advance the areas which will be likely affected by the increase of the production quantities would help reducing the potential capacity constraints, the volumes of work-in-progress and the production lead-times.

6.7 Implementation of an Enhanced Manufacturing Planning Tool

As described in one of the previous chapters, the manufacturing activities in the shop floor were controlled by the production manager and the manufacturing/operations directors through three main production planning and control spreadsheets – one for each of the main product lines:

- M10: furniture
- S10: surrounds
- K10: kitchen and other components

containing the number of units and the time data of all the work orders processed in the departments. These sheets were updated on a daily basis according to the data provided by the departments' team leaders at the end of each production shift. Also, inventory data in terms of minutes and units were automatically calculated and displayed for each machine and departments at the bottom of these spreadsheets so that the information was up-to-date every day. A few months after the beginning of the improvement programme, a critical business requirement arose in the manufacturing area of the business characterized by the need of more flexibility and product variety in terms of smaller batches, more customised items and faster customer response time. This requirement translated itself into the inadequacy of the three existing production planning spreadsheets and the urgent need of an enhanced manufacturing planning tool in order to group together all the product lines in one only spreadsheet allowing an easier control of the job work-in-progress, lead-time and machines/departments capabilities in the shop floor. A new task then was introduced consisting in the implementation of an improved manufacturing scheduling and control spreadsheet to be created on the base of the three existing spreadsheets: the "P10".

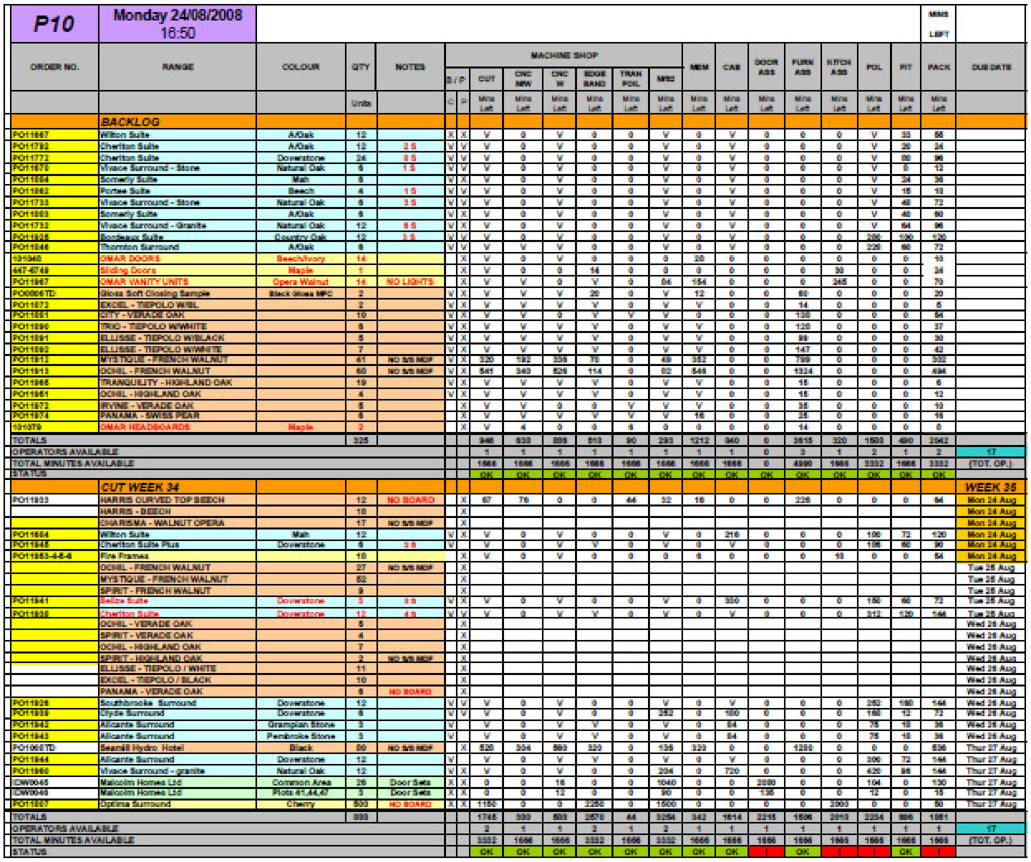
The “P10” gathered all the product lines manufactured by the company and also automatically displayed information updated on a daily basis regarding each machine/department capability in terms of minutes required and minutes available for each working week, highlighting the areas where extra capacity in terms of operators or shifts was needed in order to cope with the work loaded by the scheduling department.

The new production planning and control spreadsheet consented to constantly analyse the capacity at each machine/department in terms of minutes required and available for the job order mixes. To summarise, it allowed to:

- collect the information contained in “M10”, “S10” and “K10” in one only spreadsheet,
- compare automatically the minutes still required against the minutes available to complete the job orders for each working week in each department/machine,
- visually identify the weekly bottlenecks (machines/departments) when the minutes available were less than the minutes still required to complete the work orders, and
- quantify the extra capacity requirements (operators, backshifts).

Figure 6.40 shows the enhanced manufacturing planning spreadsheet “P10” and the comparison between the minutes required and the minutes available to complete the job orders still in progress in the shop floor.

Moreover, the new spreadsheet could create automatically graphs highlighting visual comparisons between the minutes still required and the minutes available to complete the job orders in each machine/department for a particular working week (figure 6.41) and visual comparisons between the minutes still required and the minutes available to complete the work orders in a specific department or machine for each of the working days of a particular week (figure 6.42).



	MACHINE SHOP								MEM	CAB	DOOR ASS	FURN ASS	KITCH ASS	POL	FIT	PACK	DUE DATE
	B / P		CUT	CNC M/W	CNC W	EDGE BAND	TRAN FOIL	M/S2									
	C	P	Mins Left	Mins Left	Mins Left	Mins Left	Mins Left	Mins Left	Mins Left	Mins Left	Mins Left	Mins Left	Mins Left	Mins Left	Mins Left	Mins Left	
TOTALS			1745	380	588	2570	44	3254	342	1614	2215	1506	2018	2234	696	1851	
OPERATORS AVAILABLE			2	1	1	2	1	2	1	1	1	1	1	1	1	1	17
TOTAL MINUTES AVAILABLE			3332	1666	1666	3332	1666	3332	1666	1666	1666	1666	1666	1666	1666	1666	(TOT. OP.)
STATUS			OK	OK	OK	OK	OK	OK	OK	OK	!	OK	!	!	OK	!	

Figure 6.40 – The enhanced manufacturing planning spreadsheet “P10”

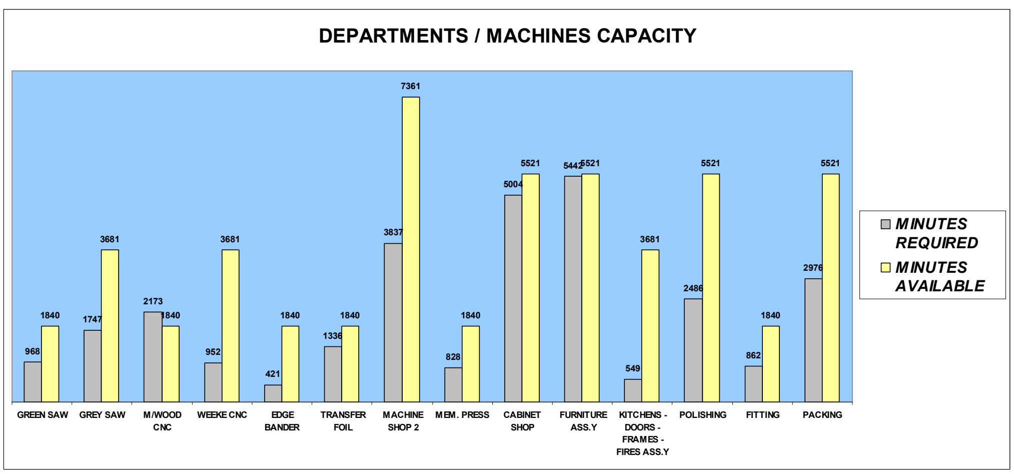


Figure 6.41 – Comparison between minutes required and available in each department

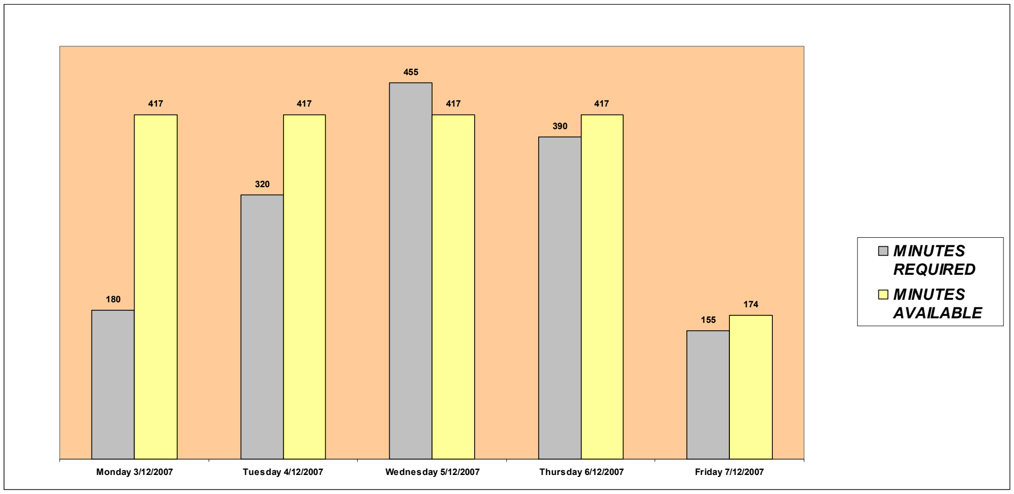


Figure 6.42 – Comparison between minutes required and available in a specific department

6.8 Quality Function Deployment (QFD) Study

An important task carried out during the improvement programme was represented by the implementation of a Quality Function Deployment (QFD) study on a product family – "fire surround" was selected as product range to carry out the study on. The analysis had as purpose the investigation across all the organization of the links in place to "connect" the customer needs with the product design and manufacturing stages. The ultimate aim of the task was to improve the existing processes in place to properly "transform" the client requirements into specific product design features and manufacturing procedures in order to obtain product specifications which were perfectly complying with the characteristics required by the final customer. It is clear that the study involved several departments and staff representatives of the company, i.e. marketing, sales, design, research & development, and manufacturing. When applying QFD at the company, it was necessary to make use of the limited resources that were available to make the project work. The initial training of the personnel involved was fundamental in order to take advantage of this limitation.

Moreover, when carrying out the task, the researcher and the QFD team involved in the exercise were fully aware of some fundamental aspects which, in different extents, affected the study. These are summarised as follows:

- QFD was a process which demanded time and it needed the appropriate planning in order to obtain beneficial results.
- It was fundamental to choose the right staff to be part of the QFD team in order to obtain a valuable outcome.
- It was required for the QFD team chosen to gain a proper knowledge of the QFD process as this helped to deal with the issues which could occur.

- The support of management was vital for the success of QFD exercise.
- Gathering the “voice of the customer” represented the main input to build the “house of quality”.
- It was important to choose adequate techniques to obtain accurate input information related to the customer requirements in order to achieve reliable results at the end of the study.

6.8.1 Steps of the Implementation

In the following are summarised the various phases of the QFD task implementation:

- Specific literature review on the subject carried out.
- Product family selected for the study: fire surrounds.
- Identification of customer requirements through structured interviews with clients, sales/marketing team and analysis of complaint data collected over a 1-year period (2008).
- Customer requirements translated first into specific products design features and then into process and operational characteristics.
- By using a "what-how" matrix, requirements of the design (the “whats”) prioritised and reconciled with the attributes embodied in the design "solution" (the “hows”); the matrix also provided the necessary information to determine the manufacturing process requirements.
- Number of charts and matrices created, the first to map the customer needs - the “what” - to the function and process that provided the need - the “how”; the correlation between the “whats” and “hows” added a “roof” to the matrix, creating a first draft of the “house of quality”.
- Manufacturing process requirements determined according to the matrix previously developed.
- Further matrices created to "propagate" the customer needs through the detailed stages of design and manufacturing processes.
- “House of quality" structure finalized according to the data collected and analyzed.
- Potential cross-discipline continuous improvement team identified and agreed with directors.
- Formal QFD training session delivered to the marketing, sales, design, and production staff; communicated the implications of QFD, particularly to the sales personnel as they were fully appraised of the service improvements delivered.
- Final recommendations proposed according to the findings of the study carried out regarding record of customer requirements and corresponding required design and manufacturing capabilities necessary to meet these requirements.

6.8.2 Customer Requirement Data

In order to have an overview of the current situation of the company regarding the customer requirement data collection, some interviews were carried out with the relevant personnel which helped to analyse what the company needed to do to obtain all the information that was required to carry out the QFD study. One of the first steps of the implementation was represented by gathering the customer requirement data. The "voice" of the customer is one of the pillars of the QFD process. It is important to emphasise that before gathering the customer need data, the QFD team analysed the different types of customers of the organization and the relative importance of the various customer categories in order to study them accordingly. At the time the study was conducted, the company was dealing with three main kinds of customers:

- The first ones were the retailers, for which the company was developing and manufacturing some standard products that they were selling to their final customer. With these kinds of products it was more difficult to know what the final customer needs were as they were not specifying any requirement. These requirements were set by the retailer.
- Another type of customer was represented by the contract customers; in this case the customers were giving the specifications for the product they required and they were expecting the company to meet these requirements. The personnel in charge of the design were involved in the creation of the drawings of the product required, which were sent to the customer for a preliminary approval. Once the customer approved it, the company was creating a sample and waiting for the customer's final approval. Finally, the model was sent to production.
- Finally, the private customers who were buying directly from the company represented only a small portion of the overall sales.

In some products, such as bathroom units, the sales person was determining how he believed the customer wanted the product. He/she was making this assumptions taking into account what was happening in the market.

It is important to emphasise that the company was not producing customized products as far as fire surrounds were concerned. The customers were choosing from existing ranges of products. Fire surrounds customization, in fact, would have been too expensive if the customer was requiring only a small amount of items, as the design team had to write new CNC machine programs for every change required by the customer.

6.8.3 Building the "House of Quality"

6.8.3.1 The Affinity Diagram

To start building the house of quality the first step was to choose a range of product, which was represented by the fire surround. Once the product had been chosen the next step was to start building the house of quality. The customer complaint data were used as main reference in order to obtain the "voice of the customer" part of the house of quality. Customer complaints represented a source of information to describe the customer needs. The company had a dedicated department which managed the complaints through a specific database. In the exercise, nearly 200 complaints were chosen from the database. Once the data sample had been chosen, the complaint data have been translated into positive phrases or concepts that represented the underlying customer needs by using the expertise of the customer's service personnel in analysing the records of the most frequent complaints and failures that caused the complaints. The outcome was represented by eight phrases which summarised the chosen complaints. Then, an affinity diagram was constructed by utilising the resulting phrases in order to group together the information collected which had some similarities on a preliminary QFD matrix. An affinity diagram is a tool that gathers large amounts of language data (ideas, opinions, issues, etc.) and organizes them into groups based on the natural relationship between each item. It is largely a creative rather than a logical process. Once the affinity diagram was completed it was used as the basis of a tree diagram. This structure was then documented in the customer requirement portion of the house of quality matrix. Subsequently, a name that represented each group of phrases/complaints was chosen and three different groups were created to represent the customer needs – performance, appearance, and functionality – which all described a different aspect of the overall "comfort" produced to the customer by the item purchased:

PERFORMANCE:

- Do not make noise
- Light working properly

APPEARANCE:

- Perfect and uniform surface
- Uniformly painted
- Has the right Size
- Clean when is delivered

FUNCTIONALITY:

- Firm joints
- Firm hearth

6.8.3.2 The Planning Matrix

The construction of the planning matrix was the next step in building the house of quality. The planning matrix is a tool which assists the QFD team to prioritize the identified customer needs. The planning matrix provides a systematic method for the development team to compare their current product performance in meeting customers' needs against the competitors' performance. The planning matrix also helps to develop a strategy for the customer satisfaction that optimizes the organization's ability to both sell the product and keep the customer satisfied. The planning matrix has a series of columns that represent key strategic product planning information and questions. Each column is associated with the answer to the following questions:

- Importance to the customer: How important is the need to the customer?
- Customer satisfaction performance: How well is the company doing in meeting this need?
- Competitive satisfaction performance: How well is the competition doing in meeting this need?
- Goal: How well the company wants to do in meeting this need with the product being developed.
- Sales point: If the company meets this need well, could they use it to help selling the product?

6.8.3.2.1 The Columns of the Planning Matrix

In the following a detailed explanation of each columns of the planning matrix:

IMPORTANCE TO THE CUSTOMER

In this column the importance of each need or benefit to the customer is recorded. There are three types of data that are commonly used in this column: absolute weight, relative weight, and ordinal importance.

- The absolute weight takes into account a "1 to 5" scaled selection of importance which is detailed as follows:

1 Not at all important to the customer,
2 Not very important to the customer,
3 Moderately important to the customer,
4 Very important to the customer,
5 Highly important to the customer.

This values are normally obtained from surveys in which the customers are asked to rate the importance of each need. This task was carried out by the company's customer service staff.

- The relative importance indicates how much more or less important one attribute is compared to another attribute. According to the relative importance if one need is twice as important as another to the customer, then the importance score of the more important need would be twice the score of the less important need. The relative importance utilises a 1-100 point scale.

- The ordinal importance indicates how much one single attribute is more or less important than another. In the ordinal importance the number 1 is assigned to the lowest-ranked customer need on each survey response. Ascending numbers are assigned to each higher ranked customer need on each response. The assigned numbers are added for each attribute in each survey response. The customer need with the highest score is the most important. The most common methods of measuring the ordinal Importance is by doing surveys to customers and asking them to rank-order the customer attributes, or to assign importance numbers to the attributes.

CUSTOMER SATISFACTION PERFORMANCE:

The customer satisfaction column in the house of quality is a 1-5 scaled measure of how the customer perceives the company's product is meeting his needs or expectations in a low or high standard. The most used method to get this information is by carrying out surveys and ask to the customer how well he feels the company's product has meet his/her needs.

COMPETITIVE SATISFACTION PERFORMANCE:

The competitive satisfaction performance describes the customer's view on how well the competitors are doing compared against the company. The customers are asked to rate how the competitors' products meet the requirements compared against the company's products. The QFD team records the competitors and the company's strengths and weaknesses. The comparison is displayed at two levels: in terms of customer needs and in terms of technical response. The measurement of this column is made by using a scale from 1 to 5.

GOAL

The goal column quantifies the QFD team's desired performance in the product to meet the customer requirements. Goal setting involves choosing which customer needs are most important. The performance goals are normally expressed in the same numerical scale as the performance levels.

IMPROVEMENT RATIO

The improvement ratio is one of the most important multipliers of importance to customers. It is a multiplication factor which scales the importance to customers. The most common method for determining the improvement ratio is to divide the goal by the current satisfaction performance:

$$\frac{\text{Goal}}{\text{Satisfaction performance}} = \text{Improvement Ratio}$$

SALES POINT

This column is linked to the ability to sell the product and it scores how well each customer need is met. In other words the sales point is a measure of how “sellable” a particular customer requirement is.

The most common values assigned for sales points are:

1.0 - No sales point

1.2 - Medium

1.5 - Strong sales points

RAW WEIGHT

The values in the raw weight column show the overall importance of each customer need to the QFD team. To calculate the raw weight it is necessary to take into account the values of the importance to the customer, the improvement ratio, and the sales point columns. In particular, it is calculated as follows:

Raw Weight = (Importance to Customer) * (Improvement Ratio) * (Sales Point)

It is important to notice that the higher the raw weight is, the more important the corresponding customer need is to the QFD team.

NORMALISED RAW WEIGHT

This column contains the weight expressed in percentage or scaled from 0 to 1. This value is obtained by dividing the raw weight by the total raw weight.

6.8.3.2.2 Building the Planning Matrix

The first step to build the planning matrix was to rate the importance of the customer requirements. The scale used was from 1 (not important) to 5 (very important). This information was obtained through to the questionnaires filled in by the sales, marketing and customer service departments’ staff. The following step was to obtain the data for the “customer satisfaction performance” and “competitive satisfaction performance” through a questionnaire in which it was asked to compare the performance of the company against the performance of two competitors based on the customer requirements. The scale that was used was from 1 (very dissatisfied) to 5 (very satisfied). The following column in the planning matrix is characterized by the goal column. In order to obtain these data, some personnel from sales and marketing was asked to score the expected goals based on the customer requirements. The next column in the planning matrix is represented by the improvement ratio which is obtained, as said, by dividing the goal by the current performance. The sales point is the following column in the planning matrix. To obtain the results the staff from sales were asked to score the values. The last column of the planning matrix is represented by the raw weight. The values of this column were obtained by multiplying the values of the importance of the customer column by the improvement ratio column by the sales point column. The Figure 6.43 shows the values which were obtained for the raw weight. The chart displays the results of the analysis of the market data and the QFD team judgements converted into figures multiplied together.

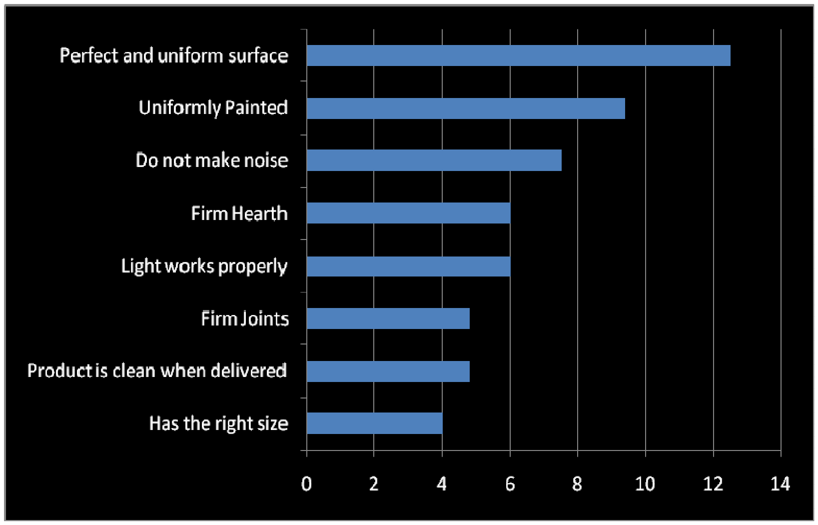


Figure 6.43 - Raw weight values

The planning matrix obtained at the end of this analysis is shown in Figure 6.44.

Customer Requirements	Importance to the customer	Customer satisfaction performance	Competitor A	Competitor B	Goal	Improvement ratio	Raw weight	Normalised weight
Do not make noise	5	4	4	4	4	1	7.5	0.136
Light works properly	4	5	5	5	5	1	6	0.109
Perfect and uniform surface	5	3	5	5	5	1.67	12.5	0.227
Uniformly Painted	5	4	5	5	5	1.25	9.37	0.170
Has the right size	3	4	4	4	4	1	4	0.07
Clean when delivered	4	5	5	5	5	1	4.8	0.08
Firm Joints	4	5	5	5	5	1	4.8	0.08
Firm Hearth	5	5	5	5	5	1	6	0.109
TOTAL							54.97	1.00

Figure 6.44 - The planning matrix

6.8.3.2.3 Analysis of the Results

According to the classification obtained in the “importance to the customer” column, the most important features for the customers that needed to be met were the ones related to the physical appearance of the fire surround. In the “customer satisfaction performance” column it could be observed that the fires surrounds produced by the company were what the customers were expecting, except from the “perfect and uniform surface” feature. In the “Competitor A” and “Competitor B” columns it was possible to see how the customers saw the competitors’ products compared to the company’s products. Here there was a balance between the customer perceptions since most of the scores were quite high and close to each other. The significant point here was that, from the customer perception, the competitors product scored a 5 in the “perfect and uniform surface” which was the lowest score obtained by the company in the “customer satisfaction performance” column. The “goals” column showed that the targets set by the company were high, but the customer perception about the company’s performance in those specific goals was slightly different. The “improvement ratio” column showed that the two main customer requirements that the company was struggling to properly meet were represented by the “perfect and uniform surface” and the “uniformly painted” features. As the chart showed after all the calculations, the main improvements that the company needed to deal with were in the field of the physical appearance of the product. This involved improving aspects such as “perfect and uniform surface” and “uniformly painted”. The results obtained showed that the company was having some problems in delivering a perfectly finished product according to the customer perception. However, the personnel at the company believed that this was just a sporadic issue. The important point here was represented by the fact that the customers perceived the flaws in the quality of the finished product. The company needed to take care of this aspect as the customers believed that the company’s competitors were doing well in this area, and this could have given them a competitive edge. Although aspects such as performance and functionality did not get high scores as the physical appearance requirements, they also needed to be taken into account by the company as they represented defects perceived by the customers in their product.

6.8.3.3 The Technical Requirements

The next step of the QFD implementation process was represented by the identification of what the customer requirements were and what had to be achieved in order to satisfy these needs. In addition, regulatory standards and requirements dictated by the management had to be identified. Once all the requirements were identified, what needed to be done to the product design to fulfil the necessary requirements was analysed. In order to obtain the technical requirements, it was used the “top-level performance measurements” method, which is a technique that provides measurements directly derived by the QFD team from the customer needs. The first step when applying this method was to define measures and measurements for each customer attribute:

- Define measures. The QFD team determined the relevance of the relationships between the measures and the customer perceptions by translating each customer need into a technical performance measure defining one or two technical performance measures for each customer attribute.
The measures were taken while the product was being developed and before it was shipped. The measure was also controlled by the QFD team by making decisions that adjusted it efficiently.
- Define measurements. It was also necessary to define how each measurement was to be performed. All the assumptions and comments which were made about each measurement were documented.

In order to develop this section of the house of quality, the design and production personnel were asked to analyse what the company had to do in terms of technical aspects to achieve the customer requirements. The balance of the analysis was moving from the "voice of the customer" to the "voice of the company". According to the analysis the design and manufacturing staff carried out, the following five preliminary measures regarding technical requirements were identified in order to better meet the customer requirements:

- Increase the numbers of suppliers.

This measure is linked to the requirement "Do not make noise". According to the company, the failures and the subsequent complaints related to the noise of the fire surrounds depend on their fire suppliers. By increasing the number of suppliers the company should expect to reduce the number of noisy fire-related issues.

- Increase number of inspections.

By increasing the number of inspections the company should reduce the problems with the joints and the hearths related to the lack of firmness and should also increase the likelihood of detecting any other kind of failures that could occur.

- Reduce time is stock.

Reducing the time in stock should reduce the likelihood for the customer to receive a product which had been damaged in the warehouse.

- Increase the drying time.

Increasing the drying time should allow the paint to dry properly and should reduce the likelihood of any possible other damage to the surface of the fire surround.

- Increase task times.

Increasing the time the operators spend on the tasks should increase the likelihood of performing the tasks better since they will have more time to carry out their work activities.

6.8.3.4 The Interrelationship Matrix

The interrelationship matrix shows the relationships between customer requirements and technical requirements. Each interrelationship cell represents a judgement, made by the QFD team, of the strength of the linkage between a substitute quality feature and a customer requirement. In QFD there are four possible interrelationships between the customer requirements and the technical characteristics:

- No interrelationship: the relationship does not exist. It means that if changes are made in the technical features of the product, there will not be any noticeable change in the customer satisfaction performance. This relationship was scored with a 0 in the matrix.
- Weak interrelationship: it occurs when a relatively large amount of changes in the technical characteristics of the product produce little or no change at all in the customer satisfaction performance. This relationship was scored with a 1 in the matrix.
- Moderate interrelationship: this kind of relationship occurs when a relatively large amount of changes in the technical features of the product produce some (but not major) changes in the customer satisfaction performance. This relationsip is scored with a 3 in the matrix.
- Strong interrelationship: this kind of relationship occurs when a relatively small amount of changes in the technical characteristics of the product produce significant changes in the customer satisfaction performance. This relationship is scored with a 9 in the matrix.

Some personnel from production were asked to analyse and complete the interrelationship matrix. Figure 6.45 shows the resulting interrelationship matrix.

Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	increase #s of suppliers	Increase "s of inspections	Reduce time in stock	Increase drying tome
Do not make noise	⊙	⊙	▲	⊙
Light Works Properly	⊙	⊙	▲	⊙
Perfect and uniform surface	▲	⊙	⊙	⊙
Uniformly painted	▲	⊙	▲	⊙
Has the right sise	▲	⊙	▲	⊙
Product is clean when delivered	▲	⊙	⊙	▲
Firm Joints	▲	⊙	○	⊙
Firm Hearth	▲	⊙	○	⊙

Figure 6.45 - The interrelationship matrix

The analysis of the interrelationship matrix showed that the requirement “do not make noise” and “light works properly” had a strong relationship with the technical requirements “Increase the number of suppliers” and “Increase the number of inspections”. Improving these two technical requirements should improve the overall customer satisfaction since, in this case, the number of fire surrounds with problems related to noise and light functions should decrease by improving the two technical requirements. The requirement “perfect and uniform surface” has a strong relationship with the technical requirements “increase the number of inspections”, “reduce the time in stock”, “increase the drying time” and “increase the time spent on the task”. This means that a considerable reduction in issues related to scratches, holes, marks and any other failures in the surface of the fire surrounds can be achieved if these technical requirements are improved. The customer requirement “uniformly painted” has a strong relationship with the customer requirements “Increase the number of inspections”, “increase the drying time” and “increase the time spent on the task”. This means that any improvement in these technical requirements should help the company to reduce issues related to a non uniform surface in the fire surrounds. The requirement “has the right size” is strongly related to the technical requirements “increase the number of inspections” and “increase the time spent on the task”. According to the interrelationship matrix, any improvement made in these two technical requirements should reduce the problems with the wrong size of the fire surrounds. By improving the technical requirements “increase the number of inspections” and “reduce the time in stock” the company should improve the chance of delivering a surface fault-free product since these two technical requirements have a strong relationship with the customer requirement “product clean when delivered”. According to the interrelationship matrix, the customer requirements “firm joints” and “firm hearth” are strongly related to technical requirements “increase the number of inspections” and “increase the time spent on task”, meaning that by improving those customer requirements the company should reduce the problems related to the failures in the joints and the hearths of the fire surrounds.

6.8.3.5 The Technical Correlations

The technical correlations are analysed in the roof of the house of quality. This matrix shows the interrelationships and independencies between the technical requirements. Here the QFD team worked through the cells by analysing the technical requirement pairs the cells represent. The aim is to identify where the technical requirements that characterize the product support or obstruct each other. For each cell the question asked was: How does improving one technical requirement affect another technical requirement?
Figure 6.46 shows the five degrees of technical correlation that are identified in QFD studies.

Strong Positive Correlation	++
Positive Correlation	+
No Correlation	<blank>
Negative Correlation	-
Strong negative Correlation	△

Figure 6.46 – The various degrees of technical correlation

The results obtained after completing the roof of the house of quality showed to the QFD implementation team where focused design improvements could produce various changes to the final product and, ultimately, positively affect the customer satisfaction level. The QFD team could also use the negative correlations identified in the analysis in order to implement solutions to those issues. The information to fill in the roof of the house of quality was gathered from some production staff. Figure 6.47 shows the resulting matrix.

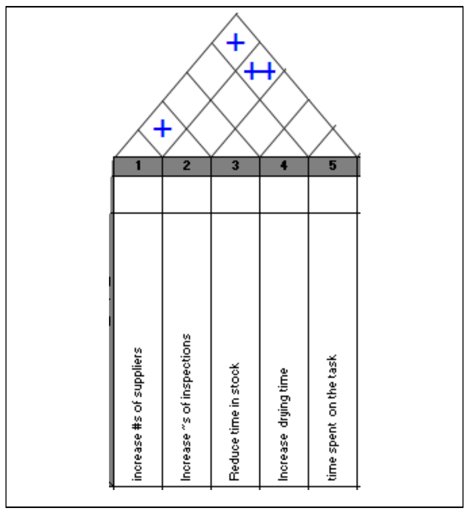


Figure 6.47 - The roof of the house of quality represented by the technical correlations

The results showed that there was a positive correlation between the “increase in the number of suppliers” and the “increase in the number of inspections”. This correlation could be explained considering that if the company increases the number of suppliers with the aim of reducing the problems with the noise level in the fire surrounds, the number of inspection might reduce. There is also a positive correlation between the “increase in the number of suppliers” and the “increase in the time spent on the tasks”. It means that if the problem with the noise is solved, the amount of time that the operator should spend on the tasks such as inspections could reduce. Finally, there is a strong positive correlation between the “increase in the number of inspections” and the “increase in the time spent on the tasks”. If the operators spend more time in their work tasks, they should achieve better results and this could also reduce the number of inspections required as the number of potential failures could decrease.

6.8.3.6 The Technical Priorities

The technical priorities represent the relative importance of each technical requirement in meeting the customer needs. They are calculated by multiplying each interrelationship weight by the overall weight in the planning matrix. Then these values have been added up in order to obtain a priority score for each technical requirement.

Figure 6.48 shows the weight in percentage that each technical requirement has in meeting the customer requirements and decreasing the complaints, and, therefore, in affecting the customer satisfaction.

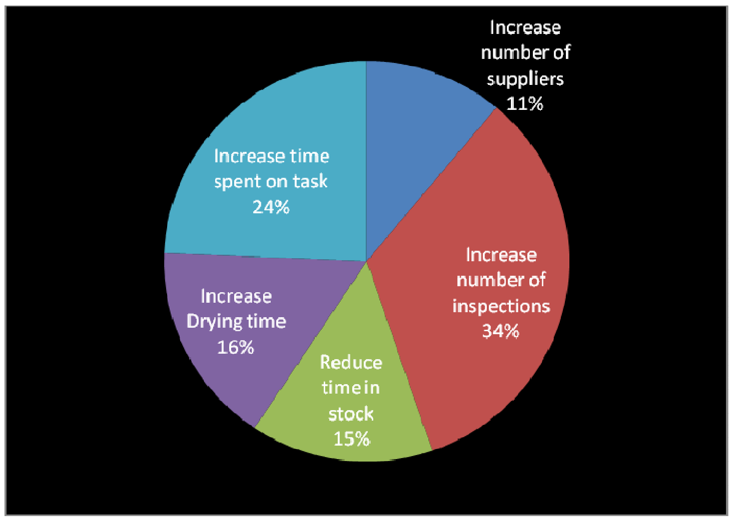


Figure 6.48 - Technical priorities in percentage

According to the results the technical requirement which obtained the highest score was “increase the number of inspections”, followed by “increase time spent on the tasks”, “reduce the time in stock”, and “increase the drying time”. The “increase the number of inspections” requirement represented 34% of the total weight. Therefore, increasing the number of inspections should highly improve the chance of meeting the customer requirements and, ultimately, increase the customer satisfaction as this technical requirement has the highest weight amongst the others.

6.8.4 The “House of Quality”

Once all the parts were had been created and analysed, they have been “assembled” to create the final structure of the house of quality, as the template in Figure 6.49 shows.

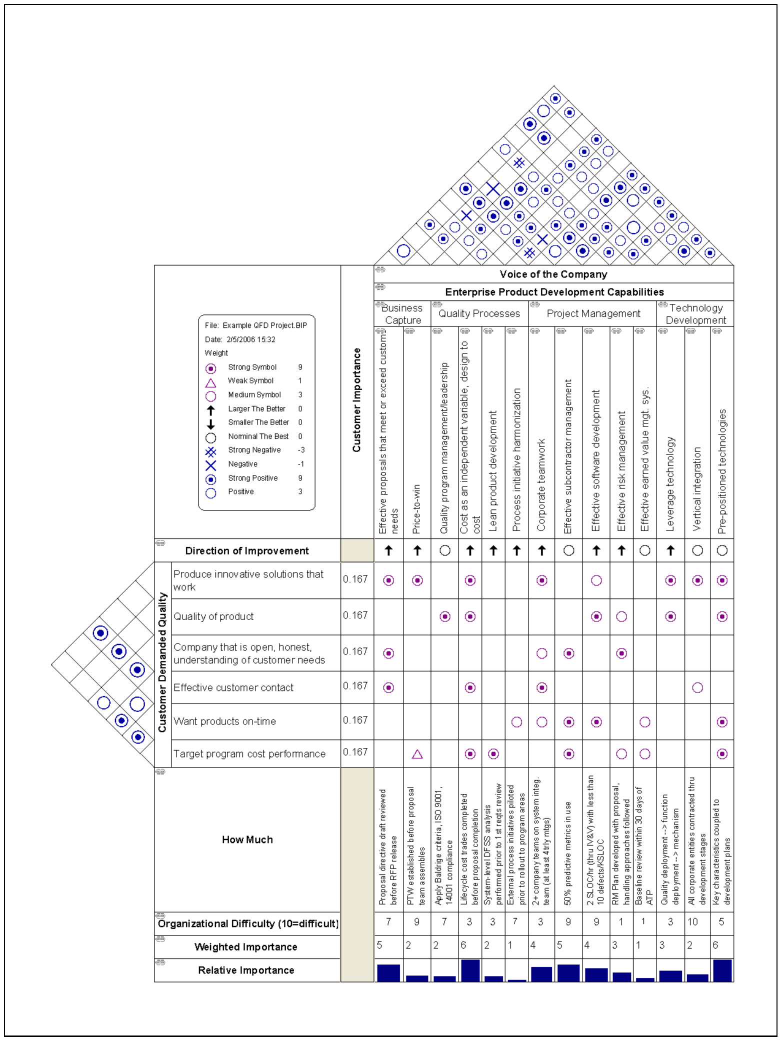


Figure 6.49 - The template of the final structure of the "house of quality"

6.9 Process Failure Mode and Effect Analysis (FMEA) Study

At a later stage of the integrated improvement programme, the values of the key performance indicators regarding reject and rework collected over the months in the shop floor have been eventually used as main input data for a Failure Mode and Effect Analysis (FMEA) study carried out in all the manufacturing departments. The Failure Mode and Effect Analysis (FMEA), whose formal applications began in the aerospace industry (mid 1960s) and it is now widely used in the automotive industry, is a "logical, structured analysis of a system, subsystem, device, or process" (Schubert, 1992) and one of the most commonly used reliability and system safety analysis techniques.

It represents a systematic tool for identifying:

- the possible failure modes of a product or process, their causes, and the effects of these failures;
- the methods to eliminate or reduce the chance of a failure occurring or re-occurring which may lead to an increase of the overall reliability and safety of a product o process.

The FMEA generates a living document that requires to be updated regularly and can be used to anticipate and prevent failures from occurring.

The FMEA can be "proactive" or "reactive":

- "Proactive FMEA" focuses on prevention of potential failures before they can occur and not on detection after they have already occurred.
  As such, FMEA is often a standard process used in the development of new products.
- "Reactive FMEA", instead, focuses on the detection after actual faults have already occurred and not on the prevention before they can occur.
  In this case, FMEA it is mainly used to improve existing production processes by decreasing the faults rate.

There are two types of FMEA, and each of them can be either "proactive" or "reactive":

- design FMEA, which examines the functions of a component, subsystem or main system - the potential failures could be, for example, an incorrect material choice or inappropriate specifications.
- process FMEA, which examines the processes used to create a component, subsystem, or main system – the potential failures could be, for example, an operator assembling part incorrectly or excess variation in process resulting in out-spec products.

The typical main terminology used in FMEA studies includes concepts such as "fault", "failure", "failure mode", and "failure effect" which are briefly defined in the following:

- fault: inability to function in a desired manner, or operation in an undesired manner, regardless of its cause;
- failure: a fault owing to breakage, wear out, compromised structural integrity, etc… ;
- failure mode: the way in which a fault or a failure occurs;
- failure effect: the consequences of a failure mode on an operation, function, status of a system/process/activity/environment, i.e. the undesirable outcome of a fault of a system element in a particular mode; the effect may be represented by relatively harmless impairment of performance, multiple fatalities, major equipment loss, environmental damage, etc… .

6.9.1 Features of the FMEA Study Conducted at the Company

The study performed at the company focused on:

- proactive and reactive process Failure Mode and Effect Analysis

by analyzing potential failures which could have been occurred (even if they never occurred and the process was working properly) and actual failures occurred in the production departments during the product manufacturing process in order to prevent them from occurring or occurring again.

The FMEA study was implemented in all the shop floor departments, i.e.:

- Machine Shop 1
- Machine Shop 2
- Surround Assembly
- Furniture Assembly
- Kitchen Assembly
- Polishing Shop
- Fire Fitting
- Packing

The approach used during the study started the investigation by taking into account smaller portions of the main system, i.e. sub-processes. This approach involved a bottom-up analysis in which the effects of possible failure modes of the sub-processes on the entire system were identified. In this study, the FMEA was not implemented in the product design stage, but in the product production phase, with the aim of identifying possible failures in the manufacturing “system”. Also, the data analysis varied in the level of detail reported in each production department, depending upon the availability of information and the detail needed to carry out the analysis. The following information was used when conducting the FMEA study within the departments:

- design drawings,
- system schematics,
- functional diagrams,
- system descriptions,
- data gained from past experience,
- manufacturer’s component data/specifications,
- preliminary hazard analysis, and
- other system analyses previously performed.

The three main FMEA variables taken into account and studied in depth for each actual or potential failure during this task are as follows:

- Severity (S): rating corresponding to the seriousness of an effect of a potential failure mode.
  Scale: 1-10.
  1: no effect on output,
  5: moderate effect,
  8: serious effect,

10: hazardous effect.

- Occurrence (O): rating corresponding to the rate at which a first level cause and its resultant failure mode will occur over the design life of the system, over the design life of the product, or before any additional process controls are applied.
Scale: 1-10.
1: failure unlikely,
5: occasional failure,
8: high numbers of failures likely,
10: failures certain.
- Detection (D): rating corresponding to the likelihood that the detection methods or current controls will detect the potential failure mode before the product is released for production for design, or for process before it leaves the production facility.
Scale: 1-10.
1: will detect failure,
5: might detect failure,
10: almost certain not to detect failures.

These three variables were then used to calculate a "Risk Priority Number (RPN)" in order to identify the greatest areas of concern and to decide a priority list of issues to tackle first. It included a thorough assessment of the:

- severity rating (S),
- occurrence rating (O), and
- detection rating (D)

for actual and potential failure modes in all the manufacturing departments of the organization.

The Risk Priority Number was calculated multiplying the severity rating by the occurrence rating by the detection rating:

- RPN = Severity Rating (S) x Occurrence Rating (O) x Detection Rating (D).

In FMEA studies, usually the corrective actions are identified and taken when:

- the risk priority number (RPN) was high, or
- the severity rating (S) was 9 or 10 (potentially hazardous failures), or
- the severity rating (S) x occurrence rating (O) score was high.

In general, there are no absolute rules for what a high risk priority number is.

The FMEA investigation carried out as part of this research study was viewed on a relative scale addressing all the failure modes identified by starting from the highest risk priority numbers (RPNs).

Prior to conducting the FMEA study, the researcher performed a functional analysis and generated FMEA cause-effect diagrams.

A functional analysis was carried out in the manufacturing department with the aim of identifying the basic and secondary functions of processes using verb-noun relationships. Basic functions are specific functions which a process is designed to do. Secondary functions are all other functions which are subordinate to the basic function.

After the functional analysis was conducted, the actual and potential failure modes were identified within each production departments as the inabilities to perform a function.

FMEA cause-effect diagrams have then been created according to the structure shown in figure 6.50, in order to identify possible causes and consequences of each failure mode analyzed.

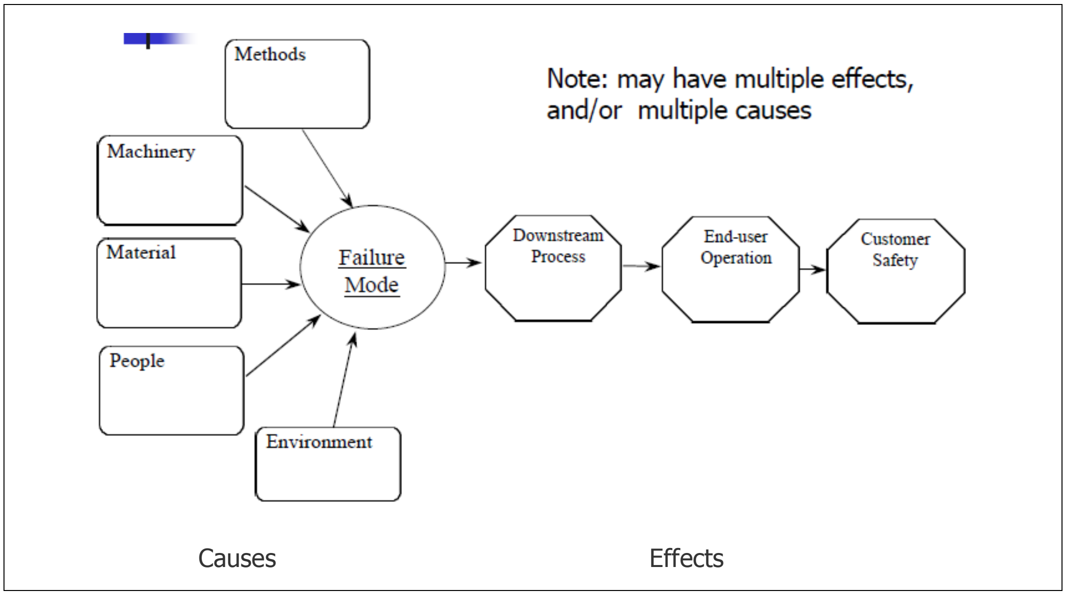


Figure 6.50 – FMEA cause-effect diagram structure

The ultimate purpose of the FMEA study was represented by a continuous improvement goal. The FMEA worksheets have, in fact, been used to identify and arrange an improvement plan by:

- recommending remedial or preventive actions,
- identifying the responsibility and the accountability to complete the actions,
- identifying target dates to complete the actions,
- listing the actions taken and reassessing the severity (S), occurrence (O) and detection (D) parameters, therefore recalculating the risk priority number (RPN).

It is also clear that the FMEA process was strongly based on a “measure - analyze - improve - control” cycle.

Finally, it is important to note that the FMEA study performed tried also to account for multiple-failure interactions, meaning that each failure was considered individually but the effect of several failures combined was also taken into consideration in the analysis.

6.9.2 Steps of the Implementation

The specific steps followed when performing the FMEA study in the departments are highlighted in the following:

- investigation of specific Failure Mode and Effect Analysis literature review ;
- definition of the scope of the analysis;
- decision on an appropriate system level at which to perform the study (system, subsystems, assembly, subassembly, component, part, etc…);
- resolution on determining the effects of failure modes on specific areas such as safety, repair cost, production lead-time, or customer satisfaction;
- decision on focus: the FMEA conducted was mainly focused on the ultimate consequences which faults could have caused on lead-time and inventory, and, subsequently, on material and labour costs, and it often indicated that a particular failure mode could have resulted in significant repair costs or downtime, without, for example, particularly impacting on safety-related issues;
- identification of appropriate FMEA implementation team within the shop floor departments' team leaders and operators trained;
- preparation and delivery of a training programme to FMEA team after the format and the content was agreed with the manufacturing director;
- creation of a report with recommendations on FMEA implementation;
- preparation of a block diagram of the manufacturing processes showing the relationship between the system's components;
- examination and documentation of the processes from acquisition of materials through part manufacture, sub-assembly, assembly, inspection, packaging, and dispatch;
- actual and potential rework data analysed with the team leaders for different manufacturing areas of the shop floor (used input also from non-conformances and observations found during quality management system internal audits)
- identification of actual and potential failure modes for each component, system or sub-system investigated;
- identification of the actual or potential causes for each failure mode (taking into consideration also and especially the "human factor");
- analysis of the effects of the failure modes (e.g. local, system, product, process effects);
- classification of the severity (S) of the effects of each failure mode;
- evaluation of the probability of occurrence (O) of each failure mode;
- identification of the likelihood of detection (D) of each failure mode;
- calculation of risk priority number (RPN) using the severity, occurrence and detection parameters estimated for each cause of failure mode;

- business case prepared in agreement with the production management team in order to justify the implementation of an appropriate corrective action plan to tackle the issues identified;
- implementation of a corrective action plan with the supervision of the department team leaders with the aim of reducing the risk of the faults occurring (for potential causes) or reoccurring (for actual causes): for each failure mode, starting from the highest priority numbers, either identification of modifications to prevent or control the failure mode or justification of the acceptance of the failure mode and its potential effects;
- where failure was due to defects within the raw materials, collaborate with the supplier to identify and eliminate the defects (when necessary, identification of alternative suppliers);
- after a set period of time, re-assessment of the severity (S), occurrence (O) and detection (D) variables and re-calculation of an updated risk priority number (RPN) in order to assess the effectiveness of the corrective action plan put in place.
- Production of a Failure Mode and Effect Analysis reference manual identifying critical areas and appropriate corrective action undertaken.

The figure 6.51 shows the general roadmap followed when conducting the FMEA study in the production department of the company.

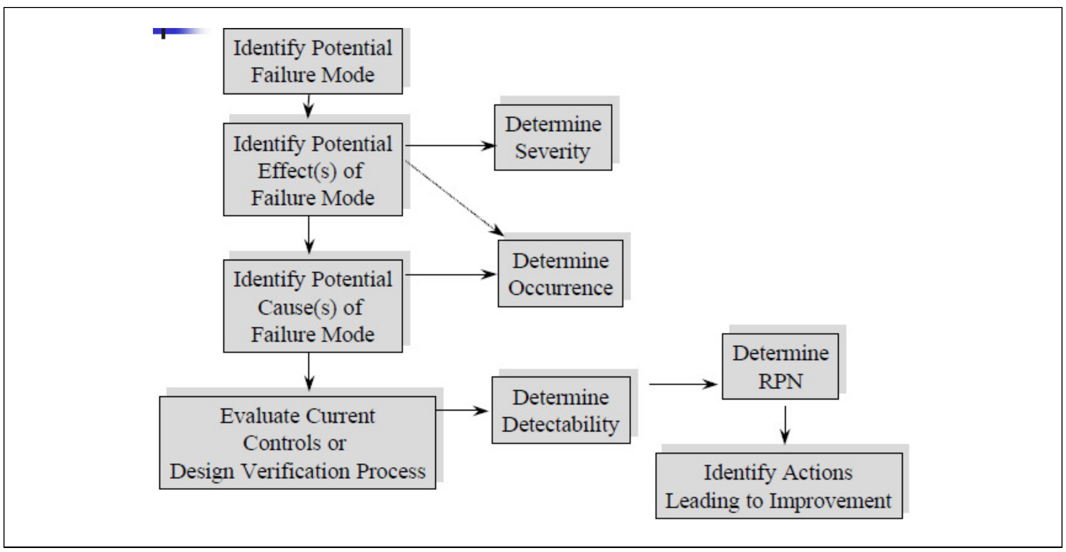


Figure 6.51 – FMEA roadmap

6.9.3 Example of the FMEA Study Performed in the Furniture Assembly Department

Figure 6.52 shows part of the FMEA worksheet compiled in the Furniture Assembly department during the FMEA study.

In particular, the potential and actual failure modes have been identified also through the data collection regarding rejects and reworks within the department. A “Pareto analysis” has been also carried out highlighting the most common actual failures occurred in the department over a 1-year period of time. For each failure mode identified, the actual and potential effects of the failure modes have been investigated and their severity parameter (S) has been scored on a 1-10 scale. For each effect of failure identified and assessed in terms of severity, the actual or potential cause of the failure modes has been analysed and its occurrence parameter (O) has been scored on a 1-10 scale. Then, for each cause of failure identified and evaluated in terms of occurrence, the current process controls in place to detect the failure modes have been highlighted and the detection parameter (D) of the cause of failure have been scored, again on a 1-10 scale. The risk priority number (RPN) values have then been calculated on a 1-1000 scale for each effect/cause of failure related to the various failure modes identified. Subsequently, recommended corrective actions have been identified with the FMEA team – manufacturing director, department team leader and some operators. As it can be noticed in the figure, in this department – Furniture Assembly, the recommendations are exclusively interventions on the root causes of failure and on the process controls in place to detect the failures, whereas it was not possible in this case to intervene on the severity of the effects of the failure modes identified. Moreover, the personnel responsibilities and accountabilities to carry out the recommendations and the target completion dates have been set.

Finally, the FMEA implementation team reviewed within the set target dates the results of the action taken by re-assessing:

- the severity (S) parameters of the effects of the failure modes identified – which did not change,
- the occurrence (O) parameters of the causes of the failure modes after the implementation of the corrective actions on the source of the faults,
- the detection (D) parameters of the failure modes through the enhanced process controls put in place after the implementation of the recommendations.

Finally, the new risk priority numbers (RPNs) have been re-calculated in order to “draw” a picture of the overall situation regarding failure mode severity, occurrence and detection in the department after the implementation of the corrective action plan.

As it can be seen in the figure, the values of the new risk priority numbers are all decreased compared to the ones before the implementation of the recommendations.

This proved the effectiveness of the FMEA study carried out and of the improvements identified and put in place in order to:

- decrease the consequences of the potential and actual failure modes identified,
- act on, and if possible eliminate, the root causes of those failures, and, finally,
- enhance the process controls in place and establish new process control methods to detect those failure modes when occurring.

Pareto Analysis	Process Steps or System Components	Failure Modes	Effects of Failure	Severity	Root Causes of Failure	Occurrence	Current Process Controls	Detection	RPN
46%	Furniture Parts (Furniture Ass.y Dept)	Wrong size parts	Error identified Job needs to be reworked/scrapped (job late)	5	Saw operator inputs wrong data into the machine and forgets to carry out final checks	4	Furniture Ass.y Dept. Initial Inspection	3	60
			Error identified Job needs to be reworked/scrapped (job late)	5	Saw operator inputs wrong data and does not carry out last-off checks because the drawings are missing	3		3	45
			Error identified Job needs to be reworked/scrapped (job late)	5	Machine inaccurate and saw operator forgets to carry out final checks	3		3	45
			Error not identified Job delivered wrong to following department	7	Saw operator inputs wrong data into the machine and forgets to carry out final checks	4		3	84
			Error not identified Job delivered wrong to following department	7	Saw operator inputs wrong data and does not carry out last-off checks because the drawings are missing	3		3	63
			Error not identified Job delivered wrong to following department	7	Machine inaccurate and saw operator forgets to carry out final checks	3		3	63
36%	Furniture Parts (Furniture Ass.y Dept)	Other Operator Error	Error identified Job needs to be reworked/scrapped (job late)	5	Machine shop operator does not realize he made a mistake when working on the part and does not carry out final inspections	4	Furniture Ass.y Dept. Initial Inspection	3	60
			Error not identified Job delivered wrong to following department	7	Machine shop operator does not realize he made a mistake when working on the part and does not carry out final inspections	4		3	84
5%	Furniture Parts (Furniture Ass.y Dept)	Unfinished Part	Error identified Job needs to be reworked/scrapped (job late)	5	Machine shop operator forgets to finish working on a part and does not carry out final checks	2	Furniture Ass.y Dept. Initial Inspection	3	30
			Error not identified Job delivered wrong to following department	7	Machine shop operator forgets to finish working on a part and does not carry out final checks	2		3	42

Figure 6.52a – First part of the FMEA worksheet of the Furniture Assembly department showing RPNs calculated before the FMEA study implementation

Pareto Analysis	Process Steps or System Components	Failure Modes	Recommended Corrective Actions	Responsibility and Target Completion Date	Action Results: Actions Taken	SEV	OCC	DET	RPN
46%	Furniture Parts (Furniture Ass.y Dept)	Wrong size parts	Make sure saw operators input correct data into the machine and carry out First-Off Last-Off Checks before moving the job to the following machine/department Instruct Ass.y Dept. to carry out thorough initial inspections on job batches	Machine Shop Team Leader - 30/11/2007	12/11/2007	5	3	2	30
			Make sure saw operators input correct data into the machine and carry out First-Off Last-Off Checks before moving the job to the following machine/department Make sure all the relevant drawings are available for the operators in the machine shop Instruct Ass.y Dept. to carry out thorough initial inspections on job batches	Machine Shop Team Leader and Development Manager - 30/11/2007	23/11/2007	5	2	2	20
			Make sure saw operators regularly conduct preventive maintenance and thoroughly check the accuracy settings of the saw before starting to work on a job, and carry out final inspections before moving the job to the following machine/department Instruct Ass.y Dept. to carry out thorough initial inspections on job batches	Machine Shop Team Leader - 30/11/2007	12/11/2007	5	2	2	20
			Make sure saw operators input correct data into the machine and carry out First-Off Last-Off Checks before moving the job to the following machine/department Instruct Ass.y Dept. to carry out thorough initial inspections on job batches	Machine Shop Team Leader - 30/11/2007	12/11/2007	7	3	2	42
			Make sure saw operators input correct data into the machine and carry out First-Off Last-Off Checks before moving the job to the following machine/department Make sure all the relevant drawings are available for the operators in the machine shop Instruct Ass.y Dept. to carry out thorough initial inspections on job batches	Machine Shop Team Leader and Development Manager - 30/11/2007	23/11/2007	7	2	2	28
			Make sure saw operators regularly conduct preventive maintenance and thoroughly check the accuracy settings of the saw before starting to work on a job, and carry out final inspections before moving the job to the following machine/department Instruct Ass.y Dept. to carry out thorough initial inspections on job batches	Machine Shop Team Leader - 30/11/2007	18/11/2007	7	2	2	28
36%	Furniture Parts (Furniture Ass.y Dept)	Other Operator Error	Make sure operators do not make mistakes wher working on the parts and carry out final inspections before moving the job to the following machine/department Instruct Ass.y Dept. to carry out thorough initial inspections on job batches	Machine Shop Team Leader - 30/11/2007	12/11/2007	5	3	2	30
			Make sure operators do not make mistakes wher working on the parts and carry out final inspections before moving the job to the following machine/department Instruct Ass.y Dept. to carry out thorough initial inspections on job batches	Machine Shop Team Leader - 30/11/2007	18/11/2007	7	3	2	42
5%	Furniture Parts (Furniture Ass.y Dept)	Unfinished Part	Make sure operators do not forget to finish working on the parts and carry out final inspections before moving the job to the following machine/department Instruct Ass.y Dept. to carry out thorough initial inspections on job batches	Machine Shop Team Leader - 30/11/2007	18/11/2007	5	2	2	20
			Make sure operators do not forget to finish working on the parts and carry out final inspections before moving the job to the following machine/department Instruct Ass.y Dept. to carry out thorough initial inspections on job batches	Machine Shop Team Leader - 30/11/2007	18/11/2007	7	2	2	28

Figure 6.52b – Second part of the FMEA worksheet of the Furniture Assembly department showing RPNs calculated after the FMEA study implementation

7 Outcomes of the Improvement Programme: Analysis of the Results of the Changes Made

7.1 Outputs

The tasks carried out during the overall improvement programme resulted in the following outputs:

- ISO 9001:2000 Quality Management System manual, procedures and record forms documented.
- Manufacturing Key Performance Indicators (KPIs) established.
- Priority improvements resulting from the method study documented in a report.
- Actual machinery capabilities manual prepared for each of the manufacturing areas investigated.
- Documented systems and procedures for the manufacturing activities from the value stream mapping conducted for the "as-is" situation; computer simulation results fully documented and final recommendations outlined.
- Enhanced production planning and control spreadsheet ("P10") created and implemented.
- Record of the customer requirements and corresponding required design and manufacturing capabilities necessary to meet these requirements as a result of the Quality Function Deployment study carried out; a Quality Function Deployment report documented to be used on an ongoing basis.
- Failure Mode and Effect Analysis training programme delivered and fully documented; Failure Mode and Effect Analysis reference manual produced identifying critical areas and appropriate corrective action for each process which can be used for future reference and fault finding. Highest priority improvements implemented; process control procedures fully documented and implemented for the monitoring and prevention of faults; cost of quality manual developed identifying the critical areas which needed improvements.

In order to translate the outputs from the partnership into project outcomes and long-term benefits, the JRG Group established regular quality circle/Kaizen-type meetings with the shop floor operators and the other relevant personnel involved with the aim of creating an ongoing sense of ownership of the concept of continuous improvement throughout the company. This also aimed to maintain the effectiveness of the project long after the project completion.

7.2 Benefits Achieved by the Company during the Programme

The main benefits accomplished by the organization after the completion of the manufacturing improvement programme can be summarised as follows:

- achievement and maintenance of the ISO9001 Quality Management System accreditation;
- **reduced manufacturing lead-time** (from 8 to 5 working days on average - see figures 6.11 and 6.12) and work-in-progress as a consequence of the introduction and monitoring of enhanced KPI's, the work method study, the value stream mapping and manufacturing process computer simulation tasks, and the implementation of a new manufacturing planning spreadsheet;
- **reduction of the material waste and rework rates** (see figures 6.18a and 6.18b) leading to improvements in product quality estimated to be 0.5% of the total raw material cost year on year, i.e. £ 12,000 after the project completion as a result of the work method study and FMEA tasks carried out;
- **accurate identification of machinery manufacturing capability** due to the introduction and monitoring of enhanced KPI's and the capability study task performed;
- **better capture of customer requirements and matching to design and manufacturing capability** leading to shorter quotation lead-times and more accurate estimates on account of the QFD task carried out.

It was estimated by the organization that these outcomes have led at the end of the 2-year programme to an **increase of the overall manufacturing efficiency** estimated through a confidential internal costing model in about 2,5% (£ 17,000) in terms of reduced lead time, work-in-progress, and rework and wastage rates.

It was finally estimated by the company that these accomplishments have also led after the project completion to **additional sales** in terms of:

- existing lines of fire surrounds of £ 530,000 (with a profit of 6.5% = £ 35,000);
- new lines of fire surrounds and internal fittings for the caravan industry of 500 units at £ 300 / unit on average (£ 150,000, with a profit of 6.5% = £ 10,000);
- new lines of fire surrounds for the new housing stock of 1500 units at 300 / unit on average (£ 450,000, with a profit of 6.5% = £ 29,000).

The improvements achieved at the completion of the project resulted from the application of the manufacturing management tools which were quite innovative to the woodworking and timber furniture industry and from the establishment of appropriate change management and people management techniques to manage continuous improvement teams and deliver culture change - typical lean/agile techniques.

7.2.1 ISO9001:2000 Quality Management System Implementation

The improvements achieved as a result of the implementation of a sustainable ISO9001:2000 Quality Management System was due to methodologies similar to QS9000 which were well established in the automotive industry, but somehow new to the woodworking sector. In the long term, the accomplishment of the ISO9001:2000 certification allowed the company's relevant personnel to enhance the control procedures over the various processes throughout the whole organization. All the company's internal procedures began to improve since the Quality Management System was driving a continuous improvement culture throughout all organization. Furthermore, the implementation of a proper manufacturing data and feedback collection system consented the JRG Group's production staff to enhance the internal information exchange and communication procedures, to better monitor the production processes in place and spot the problems, and to act more promptly upon actual and potential issues identified in the shop floor. The contribution of the accreditation has been quantifiable especially through the implementation of key performance indicators within the manufacturing departments, as it will be described in one of the next chapters. The various production measures put in place throughout the manufacturing departments showed fundamental improvements as far as waste, rework, production efficiency, work-in-progress and lead-time were concerned. Considerable improvements were also represented by a significant increase of the customer satisfaction levels and production quality perception. Finally, also the ultimate purpose of the Quality Management System implementation was achieved, since the company eventually managed to expand its customer base due to the fact that the ISO9001:2000 accreditation allowed the organization to participate to local and national tenders in a number of new markets.

7.2.2 Manufacturing Key Performance Indicators Implementation

The development and implementation of several key performance indicators within the manufacturing areas of the business allowed the organization to better monitor various aspects of the production processes in place and to enhance the control of the quality-related issues. The work-in-progress data displayed at the bottom of the three main manufacturing spreadsheets for each product line allowed the production control team – manufacturing/operations director, production manager and department team leaders – to quantify the amount of inventory still left on the floor for each machine or department in terms of minutes still required to finish the job orders or units left to complete the batches. This proved to be beneficial to the manufacturing personnel to measure the amount of work still in progress to complete the jobs and estimate reliable remaining production lead-times and deadlines for the orders to be ready to be shipped to the customers. The "key-gate" data proved to be very useful mainly to the production planning personnel since they provided it with information regarding the amount of job orders processed in each department on a weekly basis. This information was then averaged and then used in order to schedule more accurately the workload in each department of the shop floor so that it was also possible to set more realistic and achievable work targets. The lead-time data helped the scheduling staff to gather relevant information about average departmental and overall manufacturing lead-time values for the various product ranges processed in the shop floor. This allowed to forecast more realistic production lead-times and to agree with the clients more achievable delivery deadlines. The job time data collected in the shop floor were used to estimate more accurate values when deciding the weekly workload for each machine or department. Also these data proved to be fundamental to predict achievable manufacturing lead-times and to set realistic deadlines with the customers. The raw material usage data allowed to estimate more accurately the amount of each type of board used for the ranges produced. This ultimately consented the purchase department to buy the exact board quantity required to produce the jobs and to decrease the costs due to overestimating and overbuying the raw material needed to cut the work orders. The first time yield data consented the production teams to assess the weekly amount of rework and first time pass in each department. This helped to identify the manufacturing areas which needed more attention due to high level of reworks and rejects with the aim of eliminating or decreasing them. The rework and reject data have been used by the production teams to analyse the different types of fault which were occurring in the departments. This allowed to analyse the more recurrent reworks and to identify and tackle their root causes which could have been represented by different types of error – human, machine, material. This kind of analysis ultimately led to an overall decrease of the amount of reworks and rejects which were occurring in the shop floor due to the removal of the issues at the source.

7.2.3 Work Method Study

The final step of the work method study task was represented by the assessment of the outcomes after the changes in the work practices were put in place at the beam saws and the CNC machines areas of the machine shop. The analysis of the data collected after the implementation of the new work methodologies showed up immediate improvements which are described as follows:

- decrease of the job set-up and changeover times;
- increase of the available capacity of the beam saw;
- increase of the machine overall running time;
- increase of the amount of jobs processed through the machine.

Subsequently, the implementation of improved work practices and methods in critical areas of the machine shop allowed to increase the machine utilization, improve the human resources utilization and optimise the material flow, these eventually leading to the decrease of the work-in-progress and of the manufacturing lead time at the machines.

The implementation of the work method study task was eventually extended to other machines and processes in other manufacturing areas of the shop floor resulting in priority improvements such as an increase in the overall manufacturing efficiency due to an increase of the available capacity throughout all the production operations daily carried out in the shop floor.

7.2.4 Machinery Capability Study

The data of the machinery capability study task have been gathered over a period of time of few months. This allowed the researcher and the production team to carry out an analysis of the information collected in order to investigate with accuracy the manufacturing capability of some machinery, particularly focusing, as described, on the edge bander machine and the vacuum membrane press.

7.2.4.1 Edge Bander Machine

The data gathered at the edge bander machine regarding the job times have been used eventually by the manufacturing scheduling staff in order to improve the accuracy of the production planning phase.

As a result of the study, some adjustments were also made in order to increase the productivity of the machine. In particular:

- some fine adjustments were set to be optically assisted in order to achieve the changeover to different profile forms in a simple manner;
- suitable equipments were purchased to carry out automatic set-up operations with the aim of saving time and thus also costs;
- profile forms were displayed as images on the screen to allow immediate checking, prevent errors, and further decrease the set-up times;
- network connections of the PC control system were created in order to consent generating the machining programs offline and transferring them to the machine without any break in operation;
- online maintenance was established by reading fault protocols via the local area network so that the downtimes were considerably reduced.

7.2.4.2 Vacuum Membrane Press

The daily, weekly and monthly average data values collected at the vacuum membrane press have been also used to improve the manufacturing scheduling stage since at the end of the study the machine capability in terms of parts and beds processing time became known with accuracy to the production planning personnel. After the completion of the capability analysis of the machine, some improvements were put in place in order to increase the manufacturing yield through the machine especially during some periods of the year when particularly high peaks of production were expected. A multi-frame system was eventually installed on the vacuum press which permitted the machine to work on a membrane-free cycle without having to remove the membrane, giving added flexibility and production possibilities. A deeper chamber system was also installed which allowed deeper panels and curved doors to be pressed. In order to maximise the production yield and minimise the foil consumption and waste, it was also agreed with the manufacturing management team that the operators working on the membrane vacuum press had to follow specific procedures when arranging on the machine tray the components in order to ensure that the optimum loading ratio was achieved in relation to the size of the panels to be pressed. Furthermore, a second bed which was already installed on the membrane vacuum press was started being used by operating on a shuttle basis allowing one bed to be emptied and reloaded while the other bed was being pressed. This adjustment allowed to increase the production capacity of the machine especially during periods of high production volumes.
Finally, a hardware "Scan-Control" device was installed to the machine so that the tasks of the operators were reduced to only set the required pressure and pressing time values. The system was also checked by sensors positioned over the mobile press platen in order to override scanner errors. However, In case of scanner error it was always possible to exclude pistons and set pressure for each piston manually.

The "scan device" allowed to decrease the pressing time and increase the machine flexibility by automatically including or excluding pistons which were not needed in a specific pressing pattern. The "Scan-Control" system was ultimately used along with the software "Line-Control" to supervise the whole pressing process by setting working parameters, handling the menu of production, managing the alarms and displaying the production parameters.

7.2.5 Value Stream Mapping and Computer Simulation of the Manufacturing Processes

The results of the software simulation of the production of a job order mix obtained through the initial runs of the actual manufacturing scenario were compared against the outcomes of the simulation runs of the anticipated future scenario conducted using the modified model.

This consented to analyse how the changes impacted on the production processes and then to decide on the possible changes to put in place in the real manufacturing environment.

7.2.5.1 Comparison between the Simulation Run Results of the Current against the Predicted Scenario

The analysis of the comparison showed that the bottlenecks which slowed down the production process during the initial simulation runs reduced at the “Weeke” CNC machine due to the doubled capacity obtained through the introduction of a backshift.

Other capacity constraints in the machine shop 2 (at the “dimensional saws”), in the furniture and in the fire surrounds assembly departments did not occur any more since in the new manufacturing simulation model the cross-training introduced more shared resources and flexibility into the system and allowed several operators to be moved from various departments to other work centres when required.

Also the internal door manufacturing process appeared now more streamlined and the queues at the work centres involved in the process highly decreased due to the increased number of resources in terms of operators now available along the whole process. This positively impacted also on decreasing the work-in-progress of other product ranges since they needed to be processed on the same work centres which were used for the internal door manufacturing process.

7.2.5.2 Benefits Achieved after Implementing the Changes Identified

The changes identified appeared then very beneficial once applied in theory in the anticipated future manufacturing scenario and the company decided therefore to put some of them into practice right away after the simulation runs highlighted the benefits, with the aim of taking proactively countermeasures to cope with the expected market demand changes. A cross-training programme soon started involving several operators from different departments who were trained on how to operate the “dimensional saws”, the “Weeke” CNC machine, assemble furniture and fire surround units and carry out many of the work activities involved in the internal door manufacturing process. Also a backshift at the “Weeke” CNC machine was established when required by the production inventory and queues.

Some months later, towards the end of the overall improvement programme, the expected scenario simulated some months beforehand proved to be very realistic and quite accurate. The market situation started being characterized by a customer demand quite similar to the situation forecasted some months before when running the simulation model and also the product mix weekly manufactured at the company was very similar to the mix anticipated at that time. The changes identified and put in place some months before proved to be fundamental to cope with the new market situation which was accurately and realistically forecasted when the simulation runs were carried out. The production flow did not experience any major delay due to the possibility of increasing the manning capacity when and where required thanks to the cross-training carried out which made available a higher number of operators for some crucial work stations. Also backshifts were established when needed at specific work centres affected by an increase in production as a consequence of particular product mixes. As a result of the changes put in place into the production environment of the organization, it was therefore possible to achieve a more streamlined manufacturing scenario where:

- the waiting times decreased and the queues in the production departments were now fewer and faster,
- the work-in-progress at the various work centres highly reduced,
- the production lead time of the product ranges decreased on average from 8 to 5 working days (see figure 6.11 at page 123 and figure 6.12 at page 124), and, ultimately,
- almost all the product delivery dates agreed with the customer were met or even improved.

The simulation activity helped to predict behaviour based on a changed environment. This would have been otherwise impossible, since real time simulation was out of the question as the management could not stop production to carry out a real time simulation. This, in fact, would have been impractical, as there would have been no production during the simulation, as well as machines and personnel being constantly moved around to predict the best possible set-up for future scenarios.

The main benefits achieved in the short-term by the organization by using computer simulation were:

- a deep understanding of what actually characterised the manufacturing processes of the business such as work activities, relationships, capacity limits, etc…;
- a strong basis on which to identify and investigate the effects that any changes made to the manufacturing processes would have had on the production areas of the business by determining which would have been beneficial and which detrimental;
- a reduced risk of implementing changes into the real production system;
- reduced operating costs accomplished through the analysis of the current systems in place and the application of changes based on the results generated from the future scenario examination.

The simulation task helped the organization to identify critical areas in the manufacturing line. Once these problems have been identified, solutions to tackle them have been derived in order to avoid capacity constraints which would have reduced the productivity level. The task also aimed to help generating a much more informative production schedule, which allowed increased communication between sales and production staff. The model helped to identify where problems might have occurred in the shop floor, as the maximum capacity for the factory would be set, allowing target delivery times to be set much more realistically.

This task provided the organization with a simulation model that represented a basis for future changes to the company. Even at present the model developed through this task is, in fact, a fundamental tool for the company to realistically and accurately represent and analyse future manufacturing scenarios according to the forecasts of a possible customer demand and to tackle in advance potential problems. It provided the organization with the ability to anticipate and solve issues (e.g. capacity constraints) before they actually occurred in the production lines in order to help streamlining the flow of materials through the manufacturing facility, ultimately decreasing the production lead-time and meeting the customer requirement by achieving the delivery dates agreed.

The computer simulation task ultimately allowed the company to operate the factory at an almost constant rate of peak output. The company was experiencing competition from manufacturers abroad, where labour was much cheaper, and production levels could therefore be much higher. By performing this manufacturing simulation activity, the organization eventually managed to decrease the amount of inventory, to achieve faster production lead-time and to meet the delivery dates set with their clients, which was what foreign companies were also basing their successful business models on. At the same time, however, the organization managed to maintain the high quality standards of their products, which differentiated them from many of the competitive products on the marketplace.

7.2.6 Enhanced Manufacturing Planning Tool Implementation

The new manufacturing planning spreadsheets represented a very useful tool for the production scheduling personnel in the first place. The enhanced functionalities which provided – also visually – information regarding the minutes required to complete the jobs to be scheduled allowed the staff to compare these values against the department or machine capacity in terms of minutes based on the number of operators or shifts available and to increase or decrease the weekly work load accordingly in order to avoid capacity constraints in the shop floor.

The “P10” also provided huge benefits to the production control team – manufacturing/operations director, production manager and department team leaders – since it allowed to see “live” bottlenecks in the shop floor on a regular basis due to the fact that the spreadsheet was updated every day and the data displayed on the sheets represented a picture of the “live” work-in-progress and a visual comparison of the minutes available against the minutes still required to complete the job orders on the go. This consented the production staff to move operators and increase/decrease the capacity in the departments and at the machines in terms of staff or backshifts to cope with the workload constraints by increasing the minutes available in order to meet the production deadlines arranged by the scheduling personnel.

7.2.7 Quality Function Deployment (QFD) Study

It is fundamental to emphasise that the Quality Function Deployment (QFD) exercise does not finish with the construction of the house of quality. In some cases the house of quality is just one of a number of matrices which can be developed with the information gathered during the study. The final analysis and interpretation of the results of the different parts of the house of quality gave the company valuable information about its performance in specific business areas. In particular, the analysis of the results of the QFD exercise carried out helped to support the research & development, production, and sales departments by identifying the appropriate measures to be implemented and this ultimately led the company to improve its overall performance. The main outcome of the analysis of the final house of quality obtained and of the overall QFD study was that the company achieved improvements in some business areas:

- customer service information,
- knowledge of their competitors, and
- design and production processes.

7.2.7.1 Customer Service Information

During the exercise the QFD implementation team found out that complaints were the only feedback that the company was receiving from their customers. Complaints usually focused on what was wrong, so that the design and production departments were able to take the appropriate measures in order to avoid to repeat the failure in the future. The relationships with the customers were mostly based on complaints-solutions. However, complaints captured only the technical aspects of the problems. They did not focus on what the customers “were really saying”. Moreover, after the QFD study was completed, the sales personnel started to be more aware that sometimes the customers themselves were coming up with specific technical solutions to pass on to the design or manufacturing teams of the company in order to have their product requirements complied with instead of relying on the “weak” procedures or corrective actions put in place by the organization. As a consequence of these issues and of the QFD analysis, the company’s staff which was in contact with the clients started to be properly trained to listen carefully to the “voice of the customer” since very often clients had the solutions to some of their unsolved problems and they were stating their needs in terms of issues. Furthermore, the company reconsidered the format of the complaint database and the information collected. The accuracy of the information that was being captured was also reviewed. The company started to emphasise this concepts to the personnel in charge of communicating with the clients. In order to gather appropriate feedback, the company started to build a “real” added-value relationship with the customers by using tools such as interviews, focus groups, and surveys. These tools, along with the

outcomes of the QFD study performed, helped the organization to properly know not only what the customers were explicitly asking for but also what they needed "without actually saying it". This allowed to provide relevant information to the design and manufacturing personnel and to solve specific technical issues which have been occurring for some time and the company had not been able to take care of or eliminate in the past since they were unknown or it was believed they did not represent a reason of big concern for their clients.
The more accurate information obtained, therefore, started to have a major positive impact on the company as a whole since it was then possible to better transform the client requirements into proper design features and manufacturing process procedures.

7.2.7.2 Knowledge of the Competitors

During the exercise the QFD implementation team also realised that the company did not have an accurate knowledge of their competitors. The sales and marketing staff believed that they knew where the company's competition stood in the market and how it was performing from the customers' point of view. The QFD study proved that this information was not accurate enough and lacked depth. This represented an important area which needed improvement as in many aspects the organization did not know how their performance was compared to their competitors'. As a consequence of this outcome, the company started to analyse various strategies to obtain accurate information regarding the competitors' performance in the market. Strategies such as better knowing the competitors' products, visiting the competitors' shops, and talking to the competitors' customers started to be implemented within the organization after the QFD study was completed and highlighted the lack of this awareness amongst their sale and marketing personnel.

7.2.7.3 Design and Production Processes

The analysis of the QFD study also allowed to better translate the customer needs into more accurate design and manufacturing process requirements regarding the line of product chosen for the exercise – fire surrounds. As described in the previous chapters, some features were identified as being more important for the final customer satisfaction and they were linked with specific design and production requirements. These, after the QFD study completion, have been improved by implementing enhanced specific design and manufacturing procedures within the research & development and production departments with the ultimate aim of better fulfilling the client needs identified by the QFD task and increasing the overall business success in the marketplace.

7.2.8 Failure Mode and Effect Analysis (FMEA) Study

The Failure Mode and Effect Analysis (FMEA) study allowed to develop an increasingly accurate and reliable estimate of probability of failure through the thorough fault analysis carried out with the knowledge and expertise of the department team leaders and operators.
The overall reliability of the production processes improved, as shown by the decrease of the risk priority numbers (RPNs) calculated after the implementation of the corrective actions for the actual and potential faults identified in the first place. This helped the organization's manufacturing team to identify and eliminate or control dangerous failure modes, minimizing potential damages to the system and its internal and external customers. This also contributed to decrease the overall manufacturing lead-time of the products due to timely identification and correction of problems. Furthermore, after the implementation of the FMEA study, the company estimated that the material waste reduced by 0.5% of the total raw material cost due to the overall decrease of the fault occurrence. Most importantly, the quality of the final product eventually improved due to the increase of process control procedures and failure detection measures which were established after the introduction of the FMEA study and the subsequent decrease of undetected faulty products shipped to the final customers. The outcomes of the analysis carried out were also used in the preparation of diagnostic procedures and to set appropriate maintenance procedures and intervals for specific machinery in the Machine Shop 1 and 2 departments. Finally, the study allowed the researcher and the management to realise that giving responsibility and accountability of the quality inspections to the line managers would have helped increase the overall product quality. As a result of this awareness, new types of enhanced control procedures were established within all the production departments of the shop floor by spreading the responsibility amongst more production staff and by eliminating the need to put in place a lengthy final inspection process before packing. The study's results were also used as input for reliability and safety considerations of machines and procedures which were involved in the manufacturing processes.

7.3 The Benefits Expected by the Company after the Completion of the Programme

Due to the significant level of benefit achieved in the manufacturing areas of the business during the integrated improvement programme and soon after its completion as described in the previous chapters, an analysis of the anticipated commercial and financial impacts of the project during the three years after the completion of the programme was carried out.
In the following paragraphs the outcomes of this analysis is reported. The benefits have been estimated as expected commercial and financial impact in terms of increase in overall

manufacturing efficiency, decrease of material waste and rework, and increase of sales of existing and new product lines.
The impacts were targeted from each of the project outputs - each of the figures are based on a projected annual turnover of £ 9,000,000 for the first year, £ 10,000,000 for the second year and £ 12,000,000 for the third year after the project completion respectively.

7.3.1 Overall Manufacturing Efficiency

Using an internal costing model where overheads are recovered against each production hour worked, the company factored in a manufacturing efficiency percentage to cover hours paid against hours worked.
Based on this confidential formula an improved efficiency rate of 2.5% (£ 17,000) has been estimated during the first year after the completion of the project - £ 17,000 carry over plus £ 17,000 = £ 34,000.
A further 1.5% efficiency improvement has also been estimated two years after the completion of the project (£ 34,000 carry over plus £ 10,000 = £ 44,000).
Finally, a 1.0% efficiency improvement has been estimated three years after the completion of the project (£ 44,000 carry over plus £ 7,000 = £ 51,000).

7.3.2 Material Waste and Rework

The successful implementation of the Failure Mode and Effect Analysis technique will result in a reduction in material waste estimated to be 0.5% of the total raw material cost year on year.
On the basis that total raw material costs equated to 40% of annual turnover, the reduction in the cost of waste has been estimated at 0.5% of £ 3,600,000 (£ 18,000) one year after the completion of the project.
A Further reduction in the cost of waste has been estimated at 0.5% of £ 4,000,000 (£ 20,000) two years after the completion of the project.
Finally, a reduction in the cost of waste of 0.5% of £ 4,800,000 (£ 24,000) has been estimated for the third year after the completion of the project.

7.3.3 Sales of Existing Products

The forecasts predicted that as a result of the achievement of the ISO9001:2000 Quality Management System accreditation additional sales of £ 600,000 (profit 6.5% = £ 39,000) will be achieved one year after the completion of the programme.
Further additional sales have been estimated at £ 700,000 (profit 6.5% = £ 46,000) during the second year after the completion of the programme.

Finally, additional sales of £ 805,000 (profit 6.5% = £ 52,000) have been estimated for the third year after the completion of the programme.

7.3.4 Sales of New Products

It has been also estimated that for the first year after the completion of the programme the sales of new fire surrounds for new housing stock (average cost/unit of £300) will be of around 2,000 units (£ 600,000. Profit 6.5% = £ 39,000).

During the second year after the completion of the programme it has been estimated that the new sales will be of 2,500 units (£ 750,000. Profit 6.5% = £ 49,000).

Finally, during the third year after the completion of the programme it has been estimated that the new sales will be of 2,660 units (£ 798,000. Profit 6.5% = £ 52,000).

It was also estimated that the sales of new fire surrounds and interior fittings for the caravan industry (average cost/unit of £300) will be of 600 units (£ 180,000. Profit 6.5% = £ 12,000) during the first year after the completion of the project.

During the second year after the completion of the project it has been estimated that the new sales will be of 700 units (£ 210,000. Profit 6.5% = £ 14,000).

Finally, during the third year after the completion of the programme it has been estimated that the new sales will be of 1,000 units (£ 300,000. Profit 6.5% = £ 20,000).

7.4 The Benefits Achieved by the University of Strathclyde

The main reason the Knowledge Base Partner, i.e. the University of Strathclyde, participated in this partnership can be identified in the challenge of implementing such a rigorous integrated continuous improvement programme within a traditional manufacturing company that relies on 'craft' skills. Indeed, the complete process closely followed ISO9001:2000 Quality Management System that used to be attuned to the highly efficient and automated automotive industry and its application within an SME furniture manufacturer was almost unique. Currently there does not appear to be any specific case studies of applying an integrated approach such as ISO9001:2000 Quality Management System within a 'craft' based non-automotive industry. Novel insights were therefore gained relevant to labour intensive companies such as the JRG Group. These have been also directly applicable for teaching purposes in classes and for wider dissemination in published literature. Hence this partnership represented for the University of Strathclyde a unique opportunity to trial emerging areas of research, implement innovative manufacturing management techniques such as Failure Mode and Effect Analysis (FMEA) and Quality Function Deployment (QFD) within a furniture manufacturer for the first time, determine what key components of ISO9001:2000 Quality Management System are applicable to the SME sector, critically observe the introduction of contemporary continuous improvement techniques to a traditional

SME, analyze implementation problems and assess their effectiveness in a quantitative manner. The collaboration between the JRG Group and the University of Strathclyde further enhanced the relationship already well established through student projects and a KTP project completed in the recent year at the company in the new product design and development by another KTP associate and also led to future researches and other student project opportunities.

7.5 The Benefits Achieved by the Researcher

In general, by taking part in this partnership the researcher had the opportunity to put into action and develop the skills and knowledge acquired during his university studies gaining at the same time valuable experience in working within a medium sized manufacturing company and leading a structured programme involving a wide range of company staff and the associated culture change. This experience has been invaluable to the researcher in order to establish a career in the manufacturing industry since it enabled him to develop managerial and technical competencies and to enhance business acumen and communication, analytical and programme management skills.

In particular, this project provided the researcher as a KTP associate with the opportunity to learn the principles of a number of important business improvement techniques, such as FMEA (Failure Mode and Effect Analysis), QFD (Quality Function Deployment), Method Study, Process Control Procedures, Process Capability Study, and ISO 9001:2000 Quality Management System. He gained experience in their application and become well conversed with the problems experienced and solutions needed in establishing and maintaining the resulting systems and processes. The skill and knowledge gained during this partnership will be extremely useful for the researcher’s future career. In particular, as a process quality engineer, the researcher had the opportunity to receive appropriate training in FMEA, QFD, apply and deliver a training programme using acquired FMEA and QFD skills to identified project teams and gain experience in team leading (e.g. during the process FMEA analysis).

Also, this partnership provided the researcher with the opportunity to gain NVQ (National Vocational Qualification) in Management Level 4 - management competence that involves the application of knowledge in a broad range of complex, technical and professional work activities performed in a variety of contexts and with a substantial degree of autonomy and personal responsibility for the work of others and the allocation of resources. It also offered the opportunity to progress towards the “Chartered” status with a recognized professional institution, and, of course, register for this Master of Philosophy postgraduate degree at the University of Strathclyde.

Overall, the Master of Philosophy research process has been an enjoyable experience and this exercise has provided a valuable document of the journey taken by JRG Group and the researcher.

The research process has mainly developed the researcher's knowledge in two key areas:

- Manufacturing optimization techniques:

  Through the thorough literature review carried out the researcher feels he has gained a greater understanding of manufacturing optimization methods and procedures and an appreciation of the issues faced by the wider manufacturing industry and how it attempts to solve them. This achievement has also provided him with greater confidence in being involved in a real working environment in perspective on his future career development.

- Research methodology:

  One of the objectives of a Master of Philosophy degree project is to understand how to carry conduct research. Initially the researcher was not fully aware of the research process and had only little understanding on how to conduct or structure a literature review or research methodology. Now that he has been through this process he is more aware of how to carry out a research project. In this particular case study, the researcher feels that the action research methodology was an appropriate methodology and allowed the combination of both quantitative and qualitative analysis to be used. The researcher also feels that, due the nature of the KTP programme, he was in a privileged position. Indeed, he gained invaluable information, experience and perspective by having a permanent base within the company, enjoying unlimited access to all areas within it and getting involved in the actual change process rather than acting as an external observer.

8 Conclusions

8.1 Critical Reflections on the Work Carried Out during the Research Study

8.1.1 Reflections on Aspects Which Positively Affected the Project

This chapter highlights some of the main aspects of the improvement programme which, to various degrees, affected the successful implementation and accomplishment of the tasks carried out.

8.1.1.1 Value Stream Mapping (VSM)

The Value Stream Mapping (VSM) activity carried out at the start of the computer simulation task was very helpful in clearly showing the manufacturing process under investigation by using a graphical method.

For instance, this process also helped to determine the ideal storage location of raw materials and work-in-progress at the various work centres. In order to retrieve the data to input into the simulation software at the beginning of the task, a thorough investigation of the production process have been carried out by the researcher through the use of Value Stream Mapping. Once the process had been analysed, it became apparent that some of the materials were moved through the factory too many unnecessary times before being processed at the relevant work units. Moving the material around the factory represented a non-value adding process, which was costing the company money in labour. This initial observations and analyses allowed the organization to identify and modify, even before the actual computer simulation tasks was completed and the final results obtained, the best areas where to store raw materials and work-in-progress in order to minimize the job batches movements.

Overall, the Value Stream Mapping activity performed helped not only the researcher, but also the management as well as the manufacturing operators to visually see in an early stage of the programme, before the computer simulation was finalized, where the issues could have occurred and which the areas requiring more attentions were. This represented an early unexpected outcome of the simulation task which led the production personnel to act upon these early findings and successfully tackle problems such as poor storage areas, work centres locations, and material paths.

8.1.1.2 Cross-Training

Most of the tasks carried out during the research programme highlighted that the manufacturing staff was highly affected by lack of cross-training. The management, indeed, in the previous years focused on specializing the training for the individual departments in order to have a work force highly trained in specific areas. Only little attention was paid to training operators in work activities different from the ones they were supposed to carry out on a daily basis, which were believed not strictly necessary. This situation in the months before the start of the project became partially responsible for capacity constraints - high amounts of work-in-progress, long queues and, subsequently, long manufacturing lead-times - which occurred in various areas of the shop floor due to lack of trained operators to run available machines, using specific tools or equipment and work on particular batch items. This aspect affecting production was identified since the very start of the research. The management, therefore, took actions accordingly and soon started a cross-training programme when there were low production volumes in the shop floor and, consequently, the staff had some spare time. The cross-training of production personnel provided "JRG Group" with the ability to obviate the need to hire specialized temporary staff and outsource work and the option of shifting personnel around the factory to utilize all machines when needed in order to cope with increased workloads.

This long-term investment in human resources, even if time-consuming, carried out to face future potential bottlenecks proved to be fundamental also for the successful progress of the project. In fact, the operators' cross-training positively affected the whole improvement programme since it allowed to increase the resources in terms of staff available to perform many of the activities related to the project tasks. This also allowed to increase the number of operators participating to the overall research study and to gain further expertise and perspective on several aspects and issues faced during the implementation of the tasks from different people involved in different production department, which, in turn, enriched and valued even more the final outcomes and findings of each task.

8.1.1.3 Involvement of the Project's Stakeholders

Another fundamental aspect which positively affected the successful progress of the programme was represented by the availability and cooperation of all the shop floor operators and the other stakeholders involved in the research project.

The production personnel support was achieved by focused training sessions arranged at the start of the research in order to overcome an initial justified skepticism and explain to the project's stakeholders the reasons behind and the details - staff involved, timescale, etc… - of the tasks to be performed. These informative sessions allowed to achieve an initial support from the manufacturing personnel, who understood the reason why the tasks were to be conducted and the detailed development of the research.

Furthermore, a high degree of involvement was also achieved and maintained during regular meetings by encouraging the departments' team leaders – representative of the manufacturing staff - to share their views and perspectives on issues affecting production and on possible corrective actions. Moreover, the departments' team leaders were provided with a high degree of responsibility and accountability for the tasks to be performed and their successful outcomes. This gave all the project's stakeholders a sense of common goals since the manufacturing staff and management were both involved in carrying out regular reviews of the individual tasks development and agreeing on common decisions about the programme progress. These meetings were also important to establish a two-way communication system between the researcher and the production personnel with the aim of analyzing staff feedbacks and discussing the needs and requirements of the workers, understanding how this could have impacted on the task activities to be performed, and agreeing decisions on the progress accordingly. The meetings also contributed to improve the communication between the individual departments regarding manufacturing and project-related issues.

Furthermore, the positive results obtained at the early stages of the programme encouraged and motivated the production operators and, sometimes, even stimulated their own initiative in performing further investigations and data analyses when carrying out various task-related activities, which in turn allowed to complete tasks before the planned timescale and with more results depth.

This sense of participation to the research and achievement of the final outcomes made the operators aware that they could really be in the first line when it came to make a difference in improving various aspects of the manufacturing process.

This also allowed the project to run smoothly and to successfully achieve its production optimization goals with a high degree of staff cooperation, which gave the final results more depth since they were accomplished not only through the knowledge and analyses of the researcher, but also the advice and expertise of people involved "in the field" on a daily basis.

8.1.1.4 The Researcher's Privileged Position

Finally, the researcher feels that his privileged position - working from inside the company in direct contact with the operators involved on a daily basis in the manufacturing process - allowed him to successfully accomplish the project outcomes also due to the unique opportunity of applying his "external" knowledge and expertise gained through his past academic career and work experience into the industry everyday practice.

As explained in the methodology chapter, this research programme adopted a methodology called "action research", which aimed at creating a change within the company. This research method allowed a continuous collaboration between the researcher and the organization, therefore allowing knowledge and ideas to be easily transferred between the two parties. The researcher gained invaluable information through having a permanent base within the company. Many other research methodologies do not have this advantage. This privileged position gave the researcher the opportunity of being involved in the actual change process rather than acting as an external observer.

Overall, during the implementation of the project, the researcher acted as a link for the project stakeholders between theory and practice by applying within the organization's manufacturing process concepts and techniques well-established and tested in industrial environments. He feels that, in this process, he represented a valuable interface between the shop floor experience, expertise, and know-how and the optimization tools of the manufacturing industry investigated and applied during this improvement programme.

8.1.2 Issues Experienced during the Programme

This chapter highlights some of the main issues which, to different extents, affected the implementation of the various tasks of the research project.

8.1.2.1 Initial Lack of Data

One of the main reasons why the company decided to undertake an improvement programme was represented by the lack of proper procedures and measuring systems to monitor and assess the capability and performance of various manufacturing units of the business. Once such measurement systems had been established, the target was to benchmark against the internal and industry-based average values of the indicators introduced for various manufacturing areas, assess the departmental and overall performance, and, if necessary, identify ways to improve it.

In the recent months, these requirements appeared to be highly necessary in order for the organization to survive first, and then to increase its success in the extremely competitive wood furniture and components manufacturing market.

Therefore the organization decided to implement this research project with the aim, at first, of carrying out some tasks in order to improve and enhance the few and very basic production performance indicators in place in the shop floor at the start of the study and introduce more thorough procedures and systems of measurement within several production areas of the business. At a further stage, other tasks have been conducted with the scope of comparing and improving the values of some of the indicators and other production aspects under observation with the ultimate objective of enhancing the manufacturing performance of the organization.

In particular, as described in the previous chapters, the tasks carried out to introduce procedures and measures in order to assess performance and capabilities were:

- the ISO9001:2000 Quality Management System implementation, aimed at establishing and document proper processes and procedures in order to achieve specific quality level of performance and comply with the requirement of the Standard;

- Key Performance Indicators introduction, established to monitor specific aspects of production (e.g. amount of work-in-progress, job times, departmental and overall manufacturing lead-times, number of jobs completed within the individual departments, board usage, first time yield, rework and rejects, etc…);
- a Capability Study, performed in order to assess the current manufacturing capacity of specific machines which, at the time the project started, was not fully known by the company;
- an enhanced manufacturing planning spreadsheet (P10) implementation, introduced to improve the manufacturing scheduling and control stages by unifying the three existing spreadsheets into one and highlighting "live" the required against the available capacity at each machine/department;
- a Quality Function Deployment (QFD) study, carried out to thoroughly analyse the customer requirements and translate them into detailed design and manufacturing specifications.

As also described in the previous chapters, the tasks performed with the aim of analyzing, comparing and improving the values of some of the indicators and other manufacturing aspects investigated, were:

- the Work Method Study, introduced to improve the current work practices within the machine shop with the aim of decreasing the departmental job times and, ultimately, the overall production lead times;
- the Computer Simulation, performed to analyse how anticipated future production scenarios could impact on the actual manufacturing capability of the organization and act upon findings with the ultimate purpose of decrease the departmental queue times and amount of work-in-progress and, consequently, the overall production lead time;
- the Failure Mode and Effect Analysis (FMEA) study, carried out to identify the severity, occurrence and delectability of actual and potential failure modes within the manufacturing departments and identify relevant corrective actions in order to improve such parameters with aim of decreasing the overall fault rates.

As described earlier, one of the first issued encountered at the start of the research study was represented by the lack of quantitative data - only few and very basic manufacturing performance metrics were in place in the shop floor at the start of the project - within the production areas of the business to benchmark against and assess the manufacturing performance of the various production units. Hence, as explained, the need of introducing in the early stages of the improvement programme several measurement systems represented by various indicators to monitor the production performance and estimate unknown manufacturing capacities of several departments and machines in the shop floor.

These data and information became available as the research project progressed and they proved to be fundamental at a further stage when assessing the current performances and capabilities by comparing the values collected against average values over periods of time and market-related benchmarks.

The initial tasks related to the implementation of various manufacturing measurement systems, therefore, showed their crucial importance since the very beginning of the overall study by allowing the project to progress towards the later improvement stages of the programme, which have been possible to carry out and successfully accomplish only as a consequence of the existence of a well-established and tested capability and performance measurement system.

8.1.2.2 Barriers to Change and Innovation

During the development of the project, an issue was sometimes encountered - in particular during the early stages of the implementation of some of the tasks of the improvement programme – which was represented by the “resistance” to change and innovation experienced by some of the production personnel in the shop floor.

In particular, these initial “barriers” have been faced by the researcher especially when:

- implementing the ISO 9001:2000 Quality Management System by documenting and, sometimes, partially modifying the current work procedures in place at the company,
- carrying out the Work Method Study to put in place new and improved work practices within the machine shop area,
- introducing in the manufacturing departments new Key Performance Indicators and modifying and improving some of the existing ones to measure the production performance,
- implementing and using in the shop floor on a daily basis the enhanced manufacturing planning spreadsheet (P10) to schedule and monitor the production, and
- carrying out the Failure Mode and Effect Analysis (FMEA) study within the production departments and implementing corrective actions to prevent faults and reworks from re-occurring.

During the initial implementation of these tasks, the researcher experienced some “resistance” to change and innovation from some of the work force.

This issue was experienced mainly due to set ways of working: the work methods and procedures in place at the company at the start of the improvement programme, indeed, were long-time well established.

Some of the organization’s staff, who recognized the need for interventions on some manufacturing-related areas of the business to tackle the issues currently affecting production, initially did not consider the tasks to be carried out fully adequate to solve some of the problems, such as long queues and high amount of work-in-progress resulting in long production lead-times. New work methods and procedures and innovative manufacturing planning and measurement systems, indeed, were sometimes seen as difficult to implement since they were not completely known and fully understood by some of the work force, who in general preferred to carry on with the usual work arrangements and methodologies.

Moreover, some personnel did not consider the lack of proper production monitoring and measurement systems significant and responsible for some of the issues affecting the manufacturing performance.

Some personnel seemed not interested or concerned about finding the best way to solve the issues, and some other seemed not even to realize that issues were experienced in some areas of the shop floor.

In general, the work force tended to be more concerned with the implications for themselves and the changes to put in place seemed to create a sense of insecurity and different assessments of the situation, which led to disagreement over the need and justification for change as well as over the advantages and disadvantages - risks and benefits - of the tasks to perform. This initial scenario could have resulted in a high degree of inability to perform as well in the new - changed – situation, which would have, eventually, jeopardized the successful accomplishment of the ultimate objectives of the improvement programme.

As a consequence, the researcher had to pay particular attention in the way the tasks and potential changes were introduced by focusing on explaining the need for change, providing the proper information, consulting, negotiating and offering support, training and involvement, enhancing the employees' relations, and building trust and a sense of security amongst the work force.

The researcher, therefore, supported by the manufacturing management team, tackled this "barriers" by arranging, before planning and implementing the tasks, focused training session with the work force to explain in depth the cause of the problems experienced in the departments and describe the reasons why the tasks of the project were necessary to solve those issues.

Moreover, during the implementation as well as the planning stage of the programme, the researcher involved all work force in order to provide it with the adequate information regarding the tasks to carry out and to discuss ideas and new "ways forward" with the personnel who was directly experiencing the issues identified in the factory floor.

This manufacturing staff involvement allowed to agree and put in place ideal common solutions with the staff working "on the field" and overcome a certain degree of skepticism and uncertainty initially experienced about some of the tasks of the programme.

Finally, the employees welcomed the implementation of the tasks of the project and the necessary changes to put in place since they realized that change could have produced positive benefits also on themselves, such as opportunities for personal development and new work challenges as well as contributing to the overall improvement of the manufacturing areas of the business by actively participating to the programme and shaping its outcomes.

8.1.2.3 Challenges of the Production Process Computer Simulation

In order to perform the production process computer simulation task, as described in the previous chapters, the researcher had to gain knowledge and expertise of a software package called “Simul8” to construct and process a model representing the manufacturing operations carried out on the factory floor.

A training course was undertaken to this purpose at the University of Strathclyde which allowed a good grounding on how to use the software. The time spent using the software during the training course at university suggested that the software was a fairly easy package to use, which could be learnt very quickly by following a few basic rules.

However, using the software to represent an actual system, and not a theoretical one, was a much more challenging task and it took some time to determine the best approach. The main difficulty experienced by the researcher was to represent an accurate “picture” of the factory floor and create a realistic simulation process. The challenge of converting an actual production process into an accurate and realistic simulation was, indeed, a vast obstacle to overcome since the real life workings of Simul8 were never delved during the training. Much research was required to understand how the software worked, and the best approach to set up the model. Creating an accurate model which represented a real “snapshot” of the company’s manufacturing scenario was a much harder task than was originally thought and a great amount of reading and experimenting had to be conducted at the beginning of the task so that the finer points of the software could be fully understood.

Applying the real life production situation in “JRG Group” to a Simul8 model has demonstrated the number of complex issues which are connected with replicating manufacturing systems.

Many of the problems were associated with replicating operations performed on the factory floor on the software. Assembly processes were particularly difficult to model, as resources needed to be allocated to assemble only specific work items. Creating specific simulation models to represent individual production areas was a key factor here. The overall complex manufacturing processes could be solved and modelled then by integrating the individual models into one only full factory model.

Data collection for the production process was also slightly difficult, as the data had to be converted into a format that could be understood by the software. Very rarely, indeed, was the data transferred straight into the simulation without being formatted or interpreted.

The general accuracy of the model was also difficult to achieve due to the wide range of products manufactured by the company. The construction of some product families to load into the model for some of the simulation runs supported this belief and proved useful to simplify the variety of products produced by the company. Also, some of the information gathered was across differing time periods and gathered by different personnel.

Another problem was represented by the scheduling of the production weeks, as the machine shop operators could change at the last minute the batch quantity or sequence to try to avoid potential capacity constraints, which could then have not represented the same simulation run forecasted and previously loaded into the model. Moreover, the accuracy of the Simul8 model was also hampered by the data collected and the assumptions taken to format information so that it could be conveyed in the model. These discrepancies could account for some small inaccuracies within the model.

The model developed, nevertheless, formed a solid basis to help reduce the production costs of the company. Reducing these costs helped "JRG Group" to compete against companies with greater automation and reduced operating costs. The model helped the company to change set-ups and processes before making any actual change within the "real-life" context, in order to obtain a theoretically reliable and accurate forecast of possible future manufacturing scenarios. This would allow many different situations to be modeled and evaluated. The company could also use the model to test new production processes before actually introducing them into the shop floor, which would allow them, for instance, to evaluate how they would affect the manufacturing of current products. Furthermore, as also already highlighted in the previous chapters, the company could modify the model if the factory floor production processes changed as well as add in any new machinery and integrate the model with extra data to help making it more accurate. As the company grows and looks to secure more business, they could look to upgrade facilities to cope with possible extra demand.

Being such an analysis of the manufacturing processes never carried out before, the computer simulation task had the potential to be extremely beneficial since it could act as the foundation for future further tests and researches. Obviously, if more accurate data will be input, then more accurate output will be obtained for the investigation.

Therefore, as already highlighted, the simulation model created provided a strong basis on which to build and analyse the effect any changes would have on the business by determining which would be beneficial and which would be detrimental.

8.1.3 Further Reflections

8.1.3.1 Retrieving and Interpreting Data

As described earlier, most of the quantitative data analyzed during the project was not readily available at the start of the research and became available and accessible as the project progressed.

However, some basic manufacturing data and information, both quantitative and qualitative, was already available at the beginning of the programme, but in some cases difficulties were experienced by the researcher when trying to retrieve and access it, due to the lack of a company-wide systematic data collection, storage and analysis system in place.

Indeed, very often during the early stages of the improvement programme - e.g. when improving existing and implementing new production metrics - when available data was needed from the shop floor then individual employee research was relied upon, and this situation sometimes created issues regarding the interpretation, the accuracy, and the reliability of the information gathered.

8.1.3.2 Available Resources

Sometimes the researcher, when carrying out some of the tasks of the improvement programme, had to make a limited use of the company's available resources in terms of equipment and operator/machine time due to other manufacturing priorities.
During several tasks, for instance, the time of the personnel involved was limited and the training sessions carried out at the start of each task proved fundamental in order to make the most of the future limited time that the staff could have actually spent on that task.
Moreover, often equipments and machines were not available to carry out tests and data analysis during the daily shifts due to the production schedule. Sometimes this problem was overcome by the researcher by conducting some of the investigations and analyses during back shifts or working over time with some of the shop floor staff.

8.1.3.3 Factory Layout

Moreover, at the start of the programme, the analysis of the factory floor layout clearly showed that minor consideration was put towards designing the layout when the organization moved to the current premises few years before. It was apparent that some areas were located where there was "free space" with no contemplation for potential growth and for some manufacturing operations sequence. Many important production relationships were not grouped closely on the shop floor. Not only was there increased travelling time but the smooth transfer of information was hindered as well. The poor shop floor layout was also reflected by some production performance data initially collected.
This scenario was partially modified since the very start of the project due to obvious poor layout-related issues which had been occurring on the factory floor in the previous months. Further modifications have then been carried out as a consequence of the manufacturing process computer simulation task at a later stage of the programme. The performance indicators collected and analyzed at the end of the project clearly showed an improvement of the production performance reflected by the decrease of the overall manufacturing lead-time, which also proved the effectiveness of the changes to the layout put in place.

8.1.3.4 Shop Floor Miscommunication

Some communication issues arose from time to time between the management and the manufacturing personnel and within the shop floor itself. The company, as described in the

previous chapters, provided information on a regular basis to the production staff about the manufacturing scheduling through appropriate spreadsheets, but sometimes "last-minute" updates and changes were found out at the last moment only through word of mouth amongst the shop floor personnel. A similar scenario sometimes occurred when a department or production unit had to modify some work operations - which caused delays on the following work stages along the manufacturing process - and the changes were not communicated to the affected work units or departments.
These situations, besides causing obvious manufacturing issues, also affected the analyses and investigations carried out by the researcher, especially when performing the manufacturing software simulation task.

8.1.3.5 Investments Proposals

The outcome of the manufacturing software simulation highlighted the necessity for the company to invest in some extra machines and new equipments in order to cope with possible capacity constraints in future manufacturing scenarios - justified by the sale department's researches and forecasts - characterized by an increase of existing products (e.g. furniture units) and a demand of new products (e.g. timber internal doors), as described earlier on.
The computer simulation, along with the previously completed capability study and production performance indicators implementation tasks, proved crucial since it allowed the researcher and the organization to understand the current manufacturing capabilities and to realize the requirement of investments in new machinery.
The organization fully understood the outcome of the tasks and the requirement to address the manufacturing process also through such investments, however restrictions related to costs that would have been incurred limited such decisions.
The financial situation along with the industry economic climate unfortunately acted holding back the company and partially preventing it from developing further in order to gain larger market shares.

8.1.3.6 Modern Manufacturing Techniques

Since the very beginning of the project it appeared quite clear to the researcher that the organization in the previous years had little consideration of modern operations management techniques and manufacturing procedures to cope with the expanding market. No explorations into these areas have been carried out in the past years which partially resulted in the current production problems experienced by the company as described at the start of this dissertation. The beliefs of working harder, longer and faster seemed to come before investigation into proper production procedures and these concepts soon appeared quite hard to overcome. This situation, very often unconsciously and especially at the very start of

the programme, sometimes affected to various degrees several of the project tasks performed slowing down their "smooth" implementation by preventing the management as well as the production personnel from easily leaving behind well-established but obsolete production procedures and moving towards modern manufacturing techniques.
This situation clearly proved, at the start of the programme, the urgent requirement for "JRG Group" to understand the inter-relationships between its business strategy and manufacturing processes. This understanding allowed to establish a specific manufacturing strategy during the implementation of the programme and to put layout, equipment, personnel, and management decisions into context, which in turn also allowed the project to successfully accomplish its manufacturing optimizations outcomes.

8.2 Contributions to Practice and Knowledge of the Research Study

It is worth noting that, as many authors highlighted, proper research begins with a strong grounding in related literature to set the boundary of the research, it identifies an existing gap, and it proposes research questions to guide the work and address that gap.
With this perspective, the research study started with a thorough review of the existing literature on production process optimization tools and structured programmes applied within manufacturing industries.
It then identified a gap in the relevant literature by recognizing the lack of comprehensive context-specific integrated improvement programmes that look at how to enhance the production process performance of furniture manufacturing organizations.
The researcher then identified and proposed further specific research questions to investigate this topic in the context of a furniture manufacturing SME. This has led to a case study representative of the furniture manufacturing industry.

The theoretical contribution of this study is evidenced by providing answers to the research questions, answers which were not specifically found in the systematic review of the existing relevant literature.
The review of the literature on production and operations management highlighted a gap represented by the lack of documented improvement programmes conducted in manufacturing organizations within the woodworking and furniture sectors. This directed the author's attention to the specific improvement techniques and tools applied in this research project. If such integrated programmes were conducted in companies within these sectors, the relevant literature does not document them. The research questions, therefore, could not be fully answered by the literature review since only the application of individual specific optimization tools was found to be documented within the furniture manufacturing SME industry. Other kinds of integrated improvement programmes in different manufacturing sectors were instead found in the relevant literature, however they dealt with quite different

techniques and methods mixtures, whereas nothing was found regarding comprehensive, structured, and focused programmes carried out in furniture manufacturing SMEs.

The outcomes of the literature investigation, therefore, emphasized the necessity of this research study not only in order to achieve the required manufacturing process optimization by the organization, but also to fill this gap existing within the relevant academic and industrial literature by analyzing the tasks performed, the issues faced and the results obtained.

Overall, the breadth of content of the research study contributed, in terms of originality and value, the following main points to the woodworking industry practice and knowledge:

- it showed how an integrated approach to the introduction of measurement systems and production optimization techniques improved the overall manufacturing performance of a furniture manufacturing organization;
- it provided a unique case study for the introduction and implementation of a specific mixture of manufacturing optimization tools within the furniture manufacturing SME industry;
- it described the challenge and successful implementation of such a rigorous integrated continuous improvement programme within a traditional manufacturing company relying on “craft” skills which allowed novel insights to be gained relevant to a labour -intensive company;
- it filled a gap existing in the relevant literature related to the documentation of manufacturing process optimization research within furniture manufacturing SMEs.

As already mentioned, the research project closely followed the ISO9001:2000 Quality Management System implementation that used to be related to the highly efficient and automated automotive industry. Its application within an SME furniture manufacturer was, therefore, almost unique. Currently, there does not appear to be documented in the woodworking and furniture manufacturing sectors literature any specific case study of applying an integrated approach such as the ISO9001:2000 Quality Management System within a “craft” based non-automotive industry.

Hence, this study represented a unique opportunity to trial emerging areas of research, document the implementation of manufacturing management techniques such as Failure Mode and Effect Analysis (FMEA) and Quality Function Deployment (QFD) within a furniture manufacturer for the first time, determine what key components of ISO9001:2000 Quality Management System are applicable to the furniture manufacturing SME sector, critically observe the introduction of contemporary continuous improvement techniques to a traditional SME, and analyze implementation problems and assess their effectiveness in a quantitative manner.

With these perspectives this project, by focusing on the implementation of manufacturing optimization tools and techniques, has shown the issues faced and the results obtained in a very specific industrial context. However, the applicability of the research study can also be generalized within the furniture manufacturing SMEs sector and its outcomes and results can provide the base for similar investigations in other organizations within this industry with the aim of enhancing their production processes. Using this host as a case study representative of a typical furniture manufacturing SME within the United Kingdom, the research has examined problems and solutions by analyzing specific issues occurring at the company and identifying general findings applicable within the furniture manufacturing industry from the results of the analyses carried out.

The improvements achieved at the completion of the project resulted from the application of the manufacturing management tools which were quite innovative to the woodworking and timber furniture industry and from the establishment of appropriate change management and people management techniques used to manage continuous improvement teams and deliver culture change.

The general applicability of the findings of the research highlights that the manufacturing optimization methodologies implemented at the company could positively affect the production processes of other furniture manufacturing SMEs and lead to accomplish similar significant results such as the ones estimated at the end of the programme carried out at "JRG Group", i.e.:

- achievement and maintenance of the ISO9001 Quality Management System accreditation;
- **reduced manufacturing lead-time** (from 8 to 5 working days on average - see figures 6.11 and 6.12) and work-in-progress as a consequence of the introduction and monitoring of enhanced KPI's, the work method study, the value stream mapping and manufacturing process computer simulation tasks, and the implementation of a new manufacturing planning spreadsheet;
- **reduction of the material waste and rework rates** (see figures 6.18a and 6.18b) leading to improvements in product quality estimated to be 0.5% of the total raw material cost year on year, i.e. £ 12,000 after the project completion as a result of the work method study and FMEA tasks carried out;
- **accurate identification of machinery manufacturing capability** due to the introduction and monitoring of enhanced KPI's and the capability study task performed;
- **better capture of customer requirements and matching to design and manufacturing capability** leading to shorter quotation lead-times and more accurate estimates on account of the QFD task carried out.

It was estimated by the organization that these outcomes have led at the end of the 2-year programme to an **increase of the overall manufacturing efficiency** estimated through a confidential internal costing model in about 2,5% (£ 17,000) in terms of reduced lead time, work-in-progress, and rework and wastage rates.

It was finally estimated by the company that these accomplishments have also led after the project completion to **additional sales** in terms of:

- existing lines of fire surrounds of £ 530,000 (with a profit of 6.5% = £ 35,000);
- new lines of fire surrounds and internal fittings for the caravan industry of 500 units at £ 300 / unit on average (£ 150,000, with a profit of 6.5% = £ 10,000);
- new lines of fire surrounds for the new housing stock of 1500 units at 300 / unit on average (£ 450,000, with a profit of 6.5% = £ 29,000).

In particular, in today's economic global markets which are progressing towards more customized goods with little standardization, achieving the benefits of reduced production lead-time and response time to consumer demand will provide organizations with a much more competitive edge than simply reducing operating and production costs.

The computer software simulation used within this programme also represents a valuable tool which can be used by furniture manufacturing organizations to observe and understand the effects of their manufacturing operations and to improve the decision making process. Overall, the results of using computer simulation to analyze the manufacturing processes far outweigh the cost of the time dedicated to its implementation. Any time invested in computer simulation helps to avoid spending substantially more time assessing the performance of the system "on-line" and increases precious "production time".

8.3 Limitations of the Research Study

Being aware of the limitations and boundary to what a researcher can achieve during a research study strengthens the robustness of the research process and the validity of the findings. In particular, this research study has a number of limitations - related to some of the individual tasks performed during the programme - which need to be considered since they might have affected the results obtained, and, subsequently, their generalization to other furniture manufacturing SMEs.

Firstly, it is important to highlight that, as with any analysis of literature, there is inevitably an element of selection, even though the approach used consciously attempted to avoid omission and promote objectivity. Also, the literature review carried out at the start of the study was intended to be exhaustive. Nevertheless, it is probable that papers and articles that reported related/relevant material were involuntarily omitted.

Some aspects which limited to different degrees the implementation of the improvement programme have already been highlighted in one of the previous paragraphs (e.g. barriers to change and innovation, creation of the computer simulation model). However, some limitations to the data collection and analysis processes which affected some of the tasks carried out still need to be pointed out.

During the computer simulation task, in order to obtain meaningful results, the model created to reflect the manufacturing processes in place within the organization required a number of assumptions - based on knowledge and experience of the shop floor staff - to be made regarding cycle times, set-up times, operator performance, and operators' sickness and absenteeism rates which created a degree of inaccuracy to the model. When loading the data into the simulation software, other approximations were also made about the routings through the manufacturing process and about the machine times at various work centres of some jobs since items often followed specific routings but not always machine time data were available. In those cases, therefore, values from similar products or average values have been used to load the software and run the simulations.

Moreover, the Quality Function Deployment (QFD) task was performed mainly using client complaints data since information regarding thorough market researches about the customer needs were not available. For this reason, the study has been conducted by interpreting the customer complaints as customer requirement data. This assumption can be partly justified and does not decrease the value of the analyses carried out and the reliability of the findings obtained. However, when evaluating the outcomes of the study, it needs to be considered that some level of subjectivity, also due to the very nature of the task, intervened to a certain degree when the researcher interpreted the information collected form various departments' personnel.

Finally, as already mentioned, one of the major problems which came across while conducting most of the tasks, especially at the early stages of the research, was represented by the scarcity of available quantitative and, to a certain extent, also qualitative data. However, the researcher is confident that, based on his experience gained during the study at the company, the large amount of various kinds of quantitative and qualitative data gathered as the project progressed and the thorough analyses carried out during each task led to reliable and justified final results and allow to generalize them also within a broader sector such as the furniture manufacturing industry.

Moreover, the analyses carried out during the project, as per the "action research" study methodology, are based only on one company and most of the researcher's manufacturing experience is based within this company. The concepts developed during the study are based on one person's perspective of a single manufacturing process. The implementation of the production performance system and optimization techniques object of this research programme is performed at the same company, therefore providing a very narrow research base. Due to the focused and very specific nature of the case study and the fact that the research activity was based only on one case might be criticized to be insufficient to generalize the findings.

However, it was important to understand the context specific processes, activities and issues within the scope of the research in order to then contribute to knowledge and practice by generalizing, where possible, the findings. This study, by rigorously following the "action research" methodology, discovered and analyzed robust context specific insights since data was treated objectively and personal interpretations, when not required, was avoided. It is also for these reasons that the researcher feels that, on a theoretical level, the outcomes of the analyses can be generalized beyond the specific context of this case study research.

8.4 Retrospective Reflections

Some retrospective reflections are required in order to complete this extensive research study. There would be some aspects to be considered and possibly changed if the project were to be repeated.

First of all, it would be useful to develop an understanding of the relevant literature and research methodology before actually starting a research programme – instead of during its early stages - in order to save precious "research" time and focus more on the project tasks. Also, it would be helpful to contact experts in same research field and within the same industry in order to identify suitable and meaningful information sources, therefore minimizing the effort spent in the search of relevant papers, articles, books during the literature review stage of the research.

Furthermore, as far as the computer simulation task is concerned, with the benefit of hindsight there was far too much time spent during the early stages of the task on learning how to use and solving problems with the software "Simul8" - which was completely new to the researcher at the beginning of the project - and on the construction of the simulation model. This made the progress of the task slow down since the very start of the task. Having a greater knowledge, understanding and expertise of the software "Simul8" since the very start of the project, would have made the task more manageable and running "faster" and "more smoothly".

Finally, it would also be necessary to re-think the chronological sequence of the overall improvement programme tasks paying more attention to the timescale and the input needed/output provided from the individual tasks for a "smoother" progress and development of the research and theoretically disregarding, if possible, any business priority or urgent requirement of the organization.

Taking the above mentioned aspects into account, the researcher believes that the ideal structure of the now completed project should have been based on the following chronological structure and sequence of tasks:

- Manufacturing performance and capability measurement tasks implemented first:
    1 - Key Performance Indicators (KPI's) Introduction,
    2 - Capability Study,
    3 - Quality Function Deployment (QFD) Study,
    4 - New Production Planning Spreadsheet (P10) Development,
    5 - ISO9001:2000 Quality Management System Implementation.

- Manufacturing optimization tasks implemented subsequently:
    6 - Work Method Study,
    7 - Failure Mode and Effect Analysis (FMEA) Study,
    8 - Manufacturing Process Computer Simulation.

8.5 Suggestions for Further Research

The researcher believes he has achieved some interesting and original contributions to practice and knowledge through the present research study. However, the findings of the study opened up further research questions which need to be addressed through further research.

First of all, new studies could investigate further the relevant literature in order to search for - if any - and analyze the findings of other manufacturing optimization research studies carried out in similar production environment since, as already mentioned, the literature review carried out was inevitably affected by an element of selection and involuntary omission. Hence, new research and additional evidence found in literature may change the perspective and the weight of the outcomes of the present study.

Most of the new generated research questions are related to a number of limitations faced during the various tasks of the present project and described in the previous chapters. More precise results and deeper insights, indeed, would be achieved if the same tasks would be carried out at the company with more types of data and more accurate information available.

Further work could be carried out at the company on manufacturing process computer simulation by using more accurate information and data - if available – regarding machine time, cycle times, set-up times, operator performance, operators’ sickness and absenteeism rates, and product routings in order to decrease the degree of approximation adopted to complete the task in this research project and to accomplish more precise and, therefore, reliable final results.

Also, further research could focus on performing a Quality Function Deployment (QFD) study at the company by using not only complaint data, but also information retrieved from proper market researches about customer requirements. This would allow to avoid assumptions and various levels of subjectivity of the researcher in interpreting the data retrieved from the personnel involved in the task since, in this case, the information would originate from a more objective external source - the customer - without the need of any interpretations.

As far as the other individual programme tasks are concerned, the researcher feels that some other aspects should be taken into consideration during further investigations at the company, with the ultimate aim of further enhancing the overall manufacturing process of the organization.

The ISO9001 Quality Management System could be complemented at the company with the introduction of the ISO14001 Environmental Management System since the two Standards are now naturally integrated one into the other. This implementation would allow to accomplish interesting insights regarding the way the organization manages waste also in order to further reduce operative costs.

Some investigations could also be performed on the implementation of other Key Performance Indicators within some of the manufacturing departments with the aim of monitoring aspects which were not fully covered during this research, such as, for instance, operators' performance levels.

The Work Method Study and the Capability Study, although they were performed in various areas of the shop floor, they did not cover the entire manufacturing process of the company. Additional researches could be conducted to pursue improved work performances in other production departments (e.g. polishing and packing departments) and to accomplish the accurate knowledge of the capabilities of other machinery and work operations (e.g. furniture assembly operations).

The Failure Mode and Effect Analysis (FMEA) study was conducted analyzing the rework and reject data as well as taking into account possible causes of failures. Although the analyses carried out in all production departments was thorough, some potential faults might have not been taken into account. Therefore, a deeper investigation with the relevant departmental staff may be required to this regard in order to cover all the possible causes of failures which can affect the production processes in place at the company.

Finally, since the sample used in this study is specific in nature, future investigations should test the accuracy and reliability of the obtained results using other sample frames in order to accumulate more evidence and validate the findings.

In particular, new researches should test the applications and the outcomes of the tasks carried out during this project in other typical manufacturing SMEs within the woodworking and furniture production industry. Further investigations could be focused, for instance, on performing manufacturing optimization programmes featuring similar tasks, but possibly performed with more availability of initial quantitative and qualitative data and information.

Other researches could be characterized by similar production performance improvement programmes, but integrated with other tasks such as, for instance, a Statistical Process Control (SPC) study, the introduction of a Material Requirement Planning (MRP) system or a Manufacturing Resource Planning (MRPII) system, the implementation of Quick Response Manufacturing (QRM) or other "just-in-time" and "lean manufacturing" related techniques oriented towards the manufacturing process enhancement.

The researcher believes that the implementation of a number of manufacturing optimization programmes in other SMEs operating within the woodworking and furniture production sector would allow to shed more light into the topic - which appears to be required due to the scarcity of relevant literature available on the matter - and evaluate the validity of the findings of the present research study, especially in the perspective of a generalization of the final results.

9 References

Ahlstrom P. and C. Karlsson. 2000. "Sequences of Manufacturing Improvement Initiatives: The Case of Delayering". *International Journal of Operations and Production Management*. Vol. 20, no. 11. January: 1259-1277.

Azouzi R., R. Beauregard, and S. D'Amours. 2009. "Exploratory Case Studies on Manufacturing Agility in the Furniture Industry". *Management Research News*. Vol. 32, No. 5. May: 424-439.

Azzone G., C.Masella, and U. Bertele. 1991. "Design of Performance Measures for Time-Based Companies". *International Journal of Operations and Production Management* . Vol.11, No. 3. January: 77.

Badham R., K. Garrety, and C. Kirsch. 2001. "Humanistic Redesign and Technological Politics in Organizations". *Journal of Organizational Change Management*. Vol. 14, No. 1: 50–63.

Banker R., G. Potter, and R. Schroeder. 1993. "Manufacturing Performance Reporting for Continuous Quality Improvement". *Management International Review*. ABI/INFORM Global. Vol. 33. First Quarter: 69-85.

Banks R.I. and S.C. Wheelwright. 1979. "Operations versus Strategy – Trading Tomorrow for Today". *Harvard Business Review*. May/June: 112-120.

Battista P. and D. Verhun. 2000. "Customer Relationship Management". *CMA Management*. May.

Beech N.. 2005. "Research Methodology". *Strathclyde Business School, University of Strathclyde*. Glasgow, United Kingdom.

Bhim S. and S.K. Sharma. 2009. "Value Stream Mapping as a Versatile Tool for Lean Implementation: An Indian Case Study of a Manufacturing Firm". *Measuring Business Excellence*. Emerald Group Publishing Limited. Vol. 13, No. 3: 58-68.

Bititici U.S. and S.S. Nudurupati. 2002. "Using Performance Measurement to Drive Continuous Improvement". *Manufacturing Engineer*. Vol. 81, No. 5: 230–235.

Bititci, U.S., S.S. Nudurupati, T.J. Turner, and S. Creighton. 2002. "Web-Enabled Performance Measurement System: Management Implications". *International Journal of Operations and Production Management*. Vol. 22, No. 11: 1273–1287.

Blaxter L., C. Hughes, and M. Tight. 2001. "How to Research". *Open University Press.* 2nd Edition. United Kingdom.

Bossert J.L.. 1991. "Quality Function Deployment: a Practioner's Approach". *Quality Press*. Milwaukee, Wisconsin (U.S.A).

Bouchereau V. and H. Rowlands. 2000. "Methods and Techniques to Help Quality Function Deployment". *Benchmarking*. Vol. 7, No 1: 8-19.

Bourne M.. 2001. "Implementation Issues". *Handbook of Performance Measurement.* GEE Publishing. London, United Kingdom.

Bourne M. and A. Neely. 2000. "Why Performance Measurement Interventions Succeed and Sail". *Proceedings of the 2nd International Conference on Performance Measurement.* Cambridge, United Kingdom: 165–173.

Bourne M., J. Mills, M. Wilcox, A. Neely, and K. Platts. 2000. “Designing, Implementing and Updating Performance Measurement Systems”. *International Journal of Operations and Production Management*. Vol. 20, No. 7: 754–771.

Brah S. A., S.L. Tee, and B.M. Rao. 2002. “Relationship between TQM and performance of Singapore companies”. *International Journal of Quality and Reliability Management*. Vol. 19, No. 4: 356-379.

Brown N.M.. 1991. “Value Engineering Helps Improve Products at the Design Stage”. *Marketing News*. Vol. 25, No.1: 18.

Burrows P.. 1991. “In Search for the Perfect Production”. *Electronic Business*. Vol. 17,No.2: 70-4.

Cagliano R. and G. Spina. 2000. “How Improvement Programmes of Manufacturing Are Selected: The Role of Strategic Priorities and Past Experience”. *International Journal of Operations and Production Management*. Vol. 20, No. 7. January: 772.

Cao X. and E.N. Hansen. 2006. “Innovation in China's Furniture Industry”. *Forest Products Journal.* Vol. 56, No. 11/12. November: 33-42.

Caplice C. and Y. Sheffi. 1995. “A Review and Evaluation of Logistics Performance Measurement Systems”. *International Journal of Logistics Management*. Vol. 6 No. 1: 61-74.

Carrie A.. 1988. “Simulation of Manufacturing Systems”. *J. Wiley and Sons*. New York, NY (U.S.A.).

Cassens D.L. and J.P. Bradtmueller. 1996. “Characterization of the Custom Woodworking Industry”. *Forest Products Journal.* Vol. 46, No. 5. May: 29.

Chapman R.L. and P.W. Hyland. 1997. “Continuous Improvement Strategies across Selected Australian Manufacturing Sectors”. *Benchmarking for Quality Management and Technology*. Vol. 4, No. 3. January: 175.

Chase R.B., F.R. Jacobs, and N.J. Aquilano. 2006. “Operations Management for Competitive Advantage”. *11th Edition. McGraw-Hill*. New York, NY (U.S.A.).

Choi T.Y. and J.K. Liker. 1995. “Bringing Japanese Continuous Improvement Approaches to U.S. Manufacturing: The Roles of Process Orientation and Communications”. *Decision Sciences* . Vol. 26, No. 5. September: 589.

Christie M.R.P., C. Perry and J. Chamard. 2000. “Implementation of Realism in Case Study Research Methodology”. *International Council for Small Business*.

Clausing D.. 1994. “Total Quality Development”. *A Step-By-Step Guide to World-Class Concurrent Engineering*. *ASME Press*.

Clifton J.J.. 1990. “Risk Prediction”. In Keller, A.Z. and Wilson, H.C. (Eds), “Disaster Prevention”, *Planning and Limitation Unit*. University of Bradford, Bradford (United Kingdom).

Coch L. and J. French. 1948. “Overcoming Resistance to Change”. *Human Relations.* Vol. 1, No. 4: 512–532.

Cooper R.. 1994. “Quality Paradigm”. *The TQM Magazine*. Vol. 6, No. 5, January: 42.

Cooper-Mitchell M.. 1994. “Steps on the Route to Service Quality”. *Managing Service Quality*. Vol. 4, No. 1. January: 18.

Cousens A., M. Szwejczewski, and M. Sweeney. 2009. “A Process for Managing Manufacturing Flexibility”. *International Journal of Operations and Production Management*. Vol. 29, No. 4 April: 357-385.

Crosby P.B.. 1979. “Quality is Free”. *McGraw-Hill*. New York, NY (U.S.A.).

Dale B. and P. Shaw. 1990. “Failure Mode and Effects Analysis in the UK Motor Industry: A State-Of-The-Art Study”. *Quality and Reliability Engineering International*. Vol. 6: 179-88.

Dale M. and C. Best. 1988. “Quality Techniques in Action”. *Automotive Engineer*. Vol. 13, No. 4: 44-7.

Damon W. and R. Schramm. 1972. “A Simultaneous Model for Production Marketing and Finance”. *Management Science*. Vol. 19 No. 2: 161-172.

Daniels S.. 1993. “Flexible Manufacturing Systems”. *Work Study*. MCB University Press. Vol. 42, No. 5. July/August: 23-25.

Daniels S.. 1997. “Back to Basics with Productivity Techniques”. *Work Study.* MCB University Press. Vol. 46, No. 2, January: 52-57.

Davenport T.H.. 1997. “Information Ecology”. *Oxford University Press*. Oxford, United Kingdom.

Denscombe M.. 2004. “The Good Research Guide for Small-Scale Social Research Projects”. *Open University Press.* McGraw-Hill Education, 2nd Edition, United Kingdom.

Denzin N.K. and Lincoln Y.S.. 2000. “Handbook of Qualitative Research”. Second Edition. *Thousand Oaks: Sage Publications Inc*.. London, United Kingdom.

Devadasan S.R., S. Muthu, R.N. Samson, and R.A. Sankaran. 2003. Design of Total Failure Mode and Effects Analysis Programme. *The International Journal of Quality and Reliability Management*. Vol. 20, No. 4/5.January: 551-568.

Dinnie K.. 2005. “Grounded Theory / Rich Data”. Unpublished Presentation. *Strathclyde Business School, University of Strathclyde*. Glasgow, United Kingdom.

Dixon J.R. and A.J. Nanni, and T.E. Vollmann. 1990. *The New Performance Challenge – Measuring Operations for World-Class Competition.* Dow Jones-Irwin, Homewood, IL (U.S.A.)

Dong-Shang C. and P.S. Kuo-Lung. 2009. “Applying DEA to Enhance Assessment Capability of FMEA”. *The International Journal of Quality and Reliability Management*. Vol. 26, No. 6. July: 629-643.

Donovan M.. 1999. “Performance Measurement: Connecting Strategy, Operations and Actions”. *R. Michael Donovan & Co, Inc..* Framingham, MA (U.S.A.).

Draaijer D. J.. 1992. “Market Orientedness of Improvement Programmes in Manufacturing: Results from Field Study Research”. *International Journal of Operations and Production Management*. Vol. 12, No. 7,8. January: 24.

Drach B.. 1994. “Use Manufacturing Standards to Drive Continuous Cost Improvement”. *Production and Inventory Management Journal*. Vol. 35, No. 1. January: 20.

Dube L., L.M. Renaghan, and J.M. Miller. 1994. “Measuring Customer Satisfaction for Strategic management”. *Cornell Hotel and Restaurant Administration Quarterly.* Vol. 35 No.1:39–47

Dumond E.J. 1995. “Learning from the Quality Improvement Process: Experience from U.S. Manufacturing Firms”. *Production and Inventory Management Journal*. Vol. 36, No. 4. October: 7.

Easterby-Smith M., R. Thorpe and A. Lowe. 1991. “Management Research – An Introduction”. *Sage Publications*. London, United kingdom.

Easterby-Smith M., R. Thorpe, and A. Lowe. 2002. “Management Research”. *Sage Publications*. London, United kingdom.

Easterby-Smith M., Thorpe R., and Lowe A.. 2004. “Management Research”. Second Edition. *Sage Publications Inc*.. London, United Kingdom.

Easton G.S. and S.L. Jarrell. 1998. "The Effects of Total Quality Management on Corporate Performance: an Empirical Investigation". *Journal of Business*. Vol. 71 No. 2: 253-308.

Eccles R.G.. 1991. "The Performance Measurement Manifesto". *Harvard Business Review.* January–February: 131–137 and 617-35.

Edwards D.K., R.C. Edgell, and C.E. Richa. 1993. "Standard Operations - The key to Continuous Improvement in a Just-In-Time Manufacturing System". Production and Inventory Management Journal. ABI/INFORM Global. Vol. 34, No. 3. Third Quarter: 7-13.

Feeny D. and R. Plant. 2000. "IT: A Vehicle for Project Success". *Mastering Information Management*, edited by D. Marchand, T. Davenport and T. Dickson. Financial Times/Prentice Hall. London, United Kingdom: 22–26.

Fielden M.. 1990. "Data Validation". *Industrial Management and Data Systems*. Vol.90, No.4: 3-5.

Fink A.. 2005. "How to Conduct Surveys. A Step-by-Step Guide". Third Edition. *Sage Publications Inc.*. London, United Kingdom.

Franceschini F. and M. Galetto. 2004. "An Empirical Investigation of Learning Curve Composition Laws for Quality Improvement in Complex Manufacturing Plants". *Journal of Manufacturing Technology Management*. ABI/INFORM Global. Vol. 15, No. 7: 687-699.

Gattiker T.F. and L.H. Boyd. 1999. "A Cause-and-Effect Approach to Analyzing Continuous Improvement at an Electronics Manufacturing Facility". *Production and Inventory Management Journal*. Vol. 40, No. 2. April: 26-31.

Gazo R. and H.J. Quesada. 2005. "A Review of Competitive Strategies of Furniture Manufacturers". *Forest Products Journal.* Vol. 55, No. 10. October: 4-12.

Ghalayini A.M. and J.S. Noble. 1996. "The Changing Basis of Performance Measurement". *International Journal of Operations and Production Management.* Vol. 16, No. 8: 63–80.

Ginn D.M., D.V. Jones, H. Rahnejat, and M. Zairi. 1998. "The 'QFD/FMEA interface'". *European Journal of Innovation Management.* Vol.1, No. 1. January: 7-20.

Glaser B.G.. 1992. "Basis of Grounded Theory Analysis". *Sociology Press*. Mill Valley, California (U.S.A.).

Globerson S.. 1985. "Issues in Developing a Performance Criteria System for an Organisation". *International Journal of Production Research*. Vol. 23, No. 4: 639-646.

Gomez C.F., M.Y. Mahmoud, and J.V. Lisboa. 2004. "A Literature Review of Manufacturing Performance Measures and Measurement in an Organizational Context: a Framework and Direction for Future Research". *Journal of Manufacturing Technology Management*. Vol. 15, No. 6: August: 511-530.

Gomez C.F., M.Y. Mahmoud, and J.V. Lisboa. 2004. "An Examination of Manufacturing Organizations' Performance Evaluation: Analysis, Implications and a Framework for Future Research". *International Journal of Operations and Production Management* . Vol. 24, No. 5/6. May: 488-513.

Gomez C.F., M.Y. Mahmoud, and J.V. Lisboa. 2006. "Performance Measurement Practices in Manufacturing Firms: an Empirical Investigation". *Journal of Manufacturing Technology Management.* Vol. 17, No. 1/2. January: 144-167.

Gonzalez M.. 2001. "Quality Function Deployment: A Road for Listening to Customer Expectations". McGraw-Hill. New York, NY (U.S.A.).

Gonzalez M. E., G. Quesada, R. Mueller, and C.A. Mora-Monge. 2004. "QFD Strategy House: an Innovative Tool for Linking Marketing and Manufacturing Strategies". *Marketing, Intelligence & Planning*. Vol. 22 No. 3: 335-348.

Gosselin M.. 2005. “An Empirical Study of Performance Measurement in Manufacturing Firms”. *International Journal of Productivity and Performance Management*. Vol. 54, No. 5/6. July: 419-437.

Goyal S., K. Mehta, R. Kodali, and S. Deshmukh. 1995. “Simulation for the Analysis of Scheduling Rules for a Flexible Manufacturing System”. *Integrated Manufacturing Systems*. Vol. 6, No. 5: 21-26.

Greasley A.. 2004. “Simulation Modelling for Business”. *Ashgate Publishing Limited*. United Kingdom.

Greasley A.. 2004. “The Case for the Organisational Use of Simulation”. *Journal of Manufacturing Technology Management*. Vol. 15, No. 7: 560-566.

Griffing A. and J. Hauser. 1992. “Patterns of Communication among Marketing, Enginerring and Manufacturing”. *Management Science*. Vol.38, No 3: 360-373.

Griffiths A., Wall S., Zimmermann C., and Klingebiel R.. 2007. “Doing Business: The Nature of Global Trading”. In L. Lloyd-Reason and L. Sear (Eds.), “Trading Places: SMEs in a Globalising Economy – A Critical Research Handbook”. *Edward Elgar*. Cheltenham, United Kingdom.

Grunberg T.. 2003. “A Review of Improvement Methods in Manufacturing Operations”. *Work Study.* Vol. 52, No. 2/3. January : 89-93.

Grunberg T.. 2004. “Performance Improvement: Towards a Method for Finding and Prioritising Potential Performance Improvement Areas in Manufacturing Operations”. *International Journal of Productivity and Performance Management*. ABI/INFORM Global. Vol. 53, No. 1/2: 52-71.

Gummesson E.. 2000. “Qualitative Methods in Management Research”. *Sage Publications*. London, United Kingdom.

Hauser J.R. and S. Shugan. 1983. “Defensive Marketing Strategies”. *Marketing Science*. Vol. 2, No.3: 239-271.

Hayes R.H. and D.A. Garvin. 1982. “Managing as if Tomorrow Mattered”. *Harvard Business Review*: 70-79.

Hendricks K.B. and V.R. Singhal. 1996. “Quality Awards and the Market Value of the Firm: An Empirical Investigation”. *Management Science*. Vol.42 No.3: 415-436.

Hines P. and N. Rich. 1997. “The Seven Value Stream Mapping Tools”. *International Journal of Operations and Production Management*. Vol. 17: 46-64.

Hines P., N. Rich, J. Bicheno, D. Brunt, D. Taylor, C. Butterworth, and J. Sullivan. 1998. “Value Stream Management”. *The International Journal of Logistics Management*. Vol.9, No.1:25-42.

Huang G.Q. and K.L. Mak. 1998. “A Survey Report on Design for Manufacture in the UK Furniture Manufacturing Industry”. *Integrated Manufacturing Systems.* Vol. 9, No. 6. January: 383-387.

Huang S.H., J.P. Dismukes, J.S.Q. Su, G. Wang, M.A. Razzak, and D.E. Robinson. 2002. “Manufacturing System Modeling for Productivity Improvement”. *Journal of Manufacturing Systems.* ABI/INFORM Global. Vol. 21, No. 4: 249-259.

Hudson M., J.P. Bennet, A. Smart, and M. Bourne. 1999. “Performance Measurement in Planning and Control in SMEs”. *In Global Production Management*, edited by K. Mertins, O. Krause and B. Schallock. Kluwer Academic. Boston, MA (U.S.A.).

Hunter S.L., S. Bullard, and P.H. Steele. 2004. “Lean Production in the Furniture Industry: The Double D Assembly Cell”. *Forest Products Journal.* Vol. 54, No. 4. April: 32-38.

Huxham C. and Vangen S.. 2003. “Researching Organizational Practice through Action Research”. *Organization Research Methods*. Vol. 63: 383-403.

Hyland P. and J. Kennedy. 2003. “A Comparison of Manufacturing Technology Adoption in SMEs and Large Companies”. 16th Annual Conference of Small Enterprise Association of Australia and New Zealand. Hosted by University of Ballarat, Ballarat, Australia. 28 September – 1 October.

Instone F. J. and B.G. Dale. 1989. “A Case Study of the Typical Issues Involved in Quality Improvement”. *International Journal of Operations and Production Management*. Vol. 9, No. 1. January: 15.

Ireson, G., W. Coombs, F. Clyde, and Y.M. Richard. 1995, “Handbook of Reliability Engineering and Management*”.* McGraw-Hill Professional. 2nd Edition. New York, NY (U.S.A.).

Ishiwata J.. 1991. “Productivity through Process Analysis”. *Productivity Press*. Cambridge, MA (U.S.A.).

Jaworsky B. and A. Kohli. 1993. “Market Orientation: Antecedents and Consequences”. *Journal of Marketing.* Vol 57: 53-70.

Johnson H.T. and R.S. Kaplan. 1987. “Relevance Lost - The Rise and Fall of Management Accounting”. *Harvard Business School Press*, Boston, MA (U.S.A.).

Jones D. and J. Womack. 2000. “Seeing the Whole: Mapping the Extended Value Stream”. *Lean Enterprise Institute*. Cambridge, MA (U.S.A.).

Jonsson P. and M. Lesshammar. 1999. “Evaluation and Improvement of Manufacturing Performance Measurement Systems - The Role of OEE”. *International Journal of Operations and Production Management.* Vol. 19, No. 1. January: 55-78.

Kai M.T., and P.L. Chee. 2006. “Fuzzy FMEA with a Guided Rules Reduction System for Prioritization of Failures”. *The International Journal of Quality and Reliability Management. Vol. 23, No. 8.* October: 1047-1066.

Kaplan R.S.. 1983. “Measuring Manufacturing Performance: a New Challenge for Managerial Accounting Research”. *Accounting Review*. Vol. 58 No. 4: 686-703.

Kaplan R.S.. 1984. “Yesterday’s Accounting Undermines Production”. *Harvard Business Review*. Vol. 62 No. 4: 95-101.

Kennerley M. and A. Neely. 2002, “A Framework of the Factors Affecting the Evolution of Performance Measurement Systems”. *International Journal of Operations and Production Management.* Vol. 22, No. 11: 1222–1245.

Kennerley M. and A. Neely. 2003. “Measuring Performance in Changing Business Environment”. *International Journal of Operations and Production Management.* Vol. 23, Iss. 2: 213–229.

Klassen R.D.. 2000. “Just-In-Time Manufacturing and Pollution Prevention Generate Mutual Benefits in the Furniture Industry”. *Interfaces.* Vol. 30, No. 3. May: 95-106.

Knock A.. 1992. “Information Holds the Key”. York International. *The TQM Magazine*. Vol. 4 Iss. 2, April, MCB UP ltd.

Knod E.M.Jnr and Schonberger. 2001. “Operations Management Meeting: Customer’s Demands”. 7th Edition. *McGraw-Hill*. New York, NY (U.S.A.).

Knox S.. 1998. “Loyalty-Based Segmentation and the Customer Development Process”. *European Management Journal*. Vol. 16, No.6: 729–37.

Kochan T.A., J.H. Gittel, and B.A. Lautsch. 1995. “Total Quality Management and Human Resource Systems: an International Comparison”. *The International Journal of Human Resource Management*. Vol. 6, No. 2: 201–222.

Kummar K.R. and D. Sudharsan. 1988. “Defensive Marketing Strategies: an Equilibrium Analysis Based on Decoupled Response Function Models”. *Management Science*. Vol. 34, No. 7:80-85.

Lasa I.S., C.O. Laburu, and V.R. De Castro. 2008. “An Evaluation of the Value Stream Mapping Tool”. *Business Process Management Journal*. Vol. 14 No. 1: 39-52

Lebas M. and K. Euske. 2002. “A Conceptual and Operational Delineation of Performance”. *Business Performance Measurement: Theory and Practice*, edited by A. Neely. Cambridge University Press. Cambridge, United Kingdom: 65–79.

Lee-Mortimer A.. 2006. “A Lean Route to Manufacturing Survival”. *Assembly Automation*. Vol. 26, No. 4. October: 265-272.

Lee-Mortimer A.. 2008. “A Continuing Lean Journey: An Electronic Manufacturer's Adopting of Kanban”. *Assembly Automation*. Vol. 28, No. 2. April: 103-112.

Lehaney B.. 1993. “A Guide to Computer-based Simulation”. *Industrial Management and Data Systems*. Vol. 93, No. 4: 9-10.

Lewin K.. 1947. “Frontiers in Group Dynamics”. *Human Relations*. Vol. 1: 5–41.

Lewin K.. 1951. “Field Theory in Social Science”. *Harper & Row*. London, United Kingdom.

Locke E.A. and G.P. Latham. 1990. “A Theory of Goal Setting and Task Performance”. *Prentice-Hall.* Englewood Cliffs, NJ (U.S.A.).

Locke E.A. and G.P. Latham. 2002. “Building a Practically Useful Theory of Goal Setting and Task Motivation”. *American Psychologist*. Vol. 57, No. 9: 705-715.

Lu M.H., C.H. Kuei, C.N. Madu, and D. Winokur. 1994. “Integrating QFD, AHP and Benchmarking in Strategic Marketing”. *Journal of business and strategic marketing*. Vol.9, No.1: 41-50.

Lynch R.L. and K.F. Cross. 1991. “Measure up - The Essential Guide to Measuring Business Performance”. *Mandarin*. London, United Kingdom.

Maani, K E, M.S. Putterill, D.G. Sluti. 1994. “Empirical Analysis of Quality Improvement in Manufacturing”. *The International Journal of Quality and Reliability Management*. Vol. 11, No. 7. January: 19.

Marchand D., W. Kettinger, and J. Rollins. 2000. “Company Performance and IM: the View from the Top”, *In Mastering Information Management*, edited by D. Marchand, T. Davenport and T. Dickson. Financial Times/Prentice Hall. London, United Kingdom: 10–16.

Markus M.L.. 2000. “How Workers React to New Technology”. *In Mastering Information Management*, edited by D. Marchand, T. Davenport and T. Dickson. Financial Times/Prentice Hall. London, United Kingdom: 233–238.

Marr B. and A. Neely. 2002. “Balanced Scorecard Software Report”. *A business Review Publication from Cranfield School of Management with contributions by Gartner, Inc.*, CT (U.S.A.).

Martinez V. and P. Albores. 2003. “Performance Indicators for the Evaluation and Control of Research in OM: the Qualitative Research Case in Proceedings of the 3rd International Workshop on Performance Measurement”. IFIP WG 5.7 *Special Interest Group on Performance Measurement Sergio Cavalieri*: 101-110.

Maskell B.H.. 1987. “Just-in-Time Manufacturing”. *Industrial Management and Data Systems*. September: 17-20.

Maskell B.H.. 1991. “Performance Measurement for World Class Manufacturing”. *Productivity Press*. Cambridge, MA (U.S.A.).May: 48–50.

McDermott R.E., R.J. Mikulak, and M.R. Beauregard. 1996. "The Basics of FMEA". *Productivity Inc.*. Portland, OR (U.S.A.).

McNair C.J. and W. Mosconi. 1987. "Measuring Performance in an Advanced Manufacturing Environment". *Management Accounting.* Vol. 69, No. 1: 28-31.

McNurry R.. 1973. "The problem of Resistance to Change in Industry". *Changing Organizational Behavior*, edited by A. Bartlett and T. Kayser. Prentice Hall. Englewood Cliffs, NJ (U.S.A.).

Meekings A.. 1995. "Unlocking the Potential of Performance Measurement: a Practical Implementation Guide". *Public Money and Management.* October–December: 5–12.

Mendibil K.. 2003. "Designing Effective Team-Based Performance Management Systems: An Integrated Approach". Unpublished PhD. *University of Strathclyde*. Glasgow, United Kingdom.

Meredith J.R., Raturi A., Amoako-Gyampah K., and Kaplan B.. 1989. "Alternative Research Paradigms in Operations". *Journal of Operations Management*. Vol. 8, No. 4: 297-326.

Mintzberg H. and Quinn J.B.. 1992. "The Strategy Process: Concepts and Contexts". *Prentice-Hall*. New Jersey (U.S.A.).

Modarress B. and A. Ansari. 2007. "Two Dimensions in the Cost of Quality". *International Journal of Quality and Reliability Management*. Vol. 4, No. 4: 9-20.

Monden Y.. 1993. "Toyota Production System: An Integrated Approach to Just-in-Time". *Industrial Engineering and Management Press*. 2nd Edition. Norcross, GA (U.S.A.).

Moser C. and Kalton G.. 1971. "Survey Methods in Social Investigation". 1993 Edition Reprinted. *Heinemann Educational Books Limited*. London, United Kingdom.

Mulhaney A., J. Sheehan, and J. Hughes. 2004. "Using ISO9000 to Drive Continual Improvement in an SME". *The TQM Magazine*. Vol.16, No. 5. September: 325-330.

Murman E.. 2002. "Lean Enterprise Value". Palgrave, Basingstoke: 72.

Nanni A.J., R. Dixon, and T.E. Vollmann. 1992. "Integrated Performance Measurement: Management Accounting to Support the new Manufacturing Realities". *Journal of Management Accounting Research*. Vol. 4: 1-19.

Narasimhan R., M. Swink, and S.W. Kim. 2005. "An Exploratory Study of Manufacturing Practice and Performance Interrelationships: Implications for Capability Progression". *International Journal of Operations and Production Management*. Vol. 25, No. 9/10. September: 1013-1033.

Navarro J., P. Hayward, and J. Voros. 2008. "How to Solve a Wicked Problem? Furniture Foresight Case Study". *Foresight: the Journal of Futures Studies, Strategic Thinking and Policy.* Vol. 10, No. 2. March: 11-29.

Neely A., H. Richards, J. Mills, K. Platts, and M. Bourne. 1997. "Designing Performance Measures: a Structured Approach". *International Journal of Operations and Production Management*. Vol. 17, No. 11. January: 1131-1152.

Nenadál J... 2008. "Process Performance Measurement in Manufacturing Organizations". *International Journal of Productivity and Performance Management* . Vol. 57, No. 6. August: 460-467.

Nudurupati, S.S. and U.S. Bititci. 2000. "Review of Performance Management Information Systems (PerforMIS)". *Internal Report for the Centre for Strategic Manufacturing.* Department of Design, Manufacture and Engineering Management, University of Strathclyde, Glasgow (United kingdom).

Nudurupati, S.S. and U.S. Bititci. 2003. "Implementation and Impact of IT Performance Measurement". *IFIP 3rd International Workshop.* Bergamo, Italy, 19–20 June.

O'Kane S., A. Papadoukakis, and D. Hunter. 2007. "Simulation Usage in SMEs". *Journal of Small Business and Enterprise Development*. Vol. 14, No. 3: 514-527.

Ong N.S.. 1997. "Productivity Improvements for a Small "Made-to-Order" Manufacturing Environment". *Industrial Management and Data Systems*. Vol. 97, No. 7. January: 251-258.

Orlikowski W.J.. 1996. "Improvising Organisational Transformation over Time: a Situated Change Perspective". *Information Systems Research.* Vol. 7, No.1: 63–92.

Patterson D.W. and R.B. Anderson. 1996. "Use of Statistical Process Control in the Furniture and Cabinet Industries". *Forest Products Journal.* Vol. 46, No. 1. January: 36.

Pheng L.S. and D. Wee. 2001. "Improving maintenance and Reducing Building Defects through ISO 9000". *Journal of Quality in Maintenance Engineering* . Vol. 7, No. 1. January: 6-24.

Prabhu B., A. Surekha, A. Holla, and K. Patel. 2008. "Value Stream Mapping of Truck Operations: A Case Study". *South Asian Journal of Management*. Vol.15, No. 2. April: 107-115.

Prahalad C.K. and M.S. Krishnan. 2002. "The Dynamic Synchronization of Strategy and Information Technology". *MIT Sloan Management Review*. Summer: 24–33.

Prasad B.. 1995. "A Structured Approach to Product and Process Optimization for Manufacturing and Service Industries". *The International Journal of Quality and Reliability Management.* Bradford. Vol. 12, Iss. 9. January: 123-138.

Prather C.W.. 2005. "The Dumb Thing about SMART Goals for Innovation". *Research Technology Management*. Vol. 48, No. 5. September: 14-15.

Puente J., R. Pino, P. Priore, and D. De La Fuente. 2002. "A decision Support System for Applying Failure Mode and Effects Analysis". *The International Journal of Quality and Reliability Management.* Vol. 19, No. 2/3. January: 137-150.

Quesada H. and R. Gazo. 2003. "Development of a Manufacturing System for Construction of School Furniture". *Forest Products Journal.* Vol. 53, No. 9. September: 47-54.

Quesada H.and R. Gazo. 2007. "Methodology for Determining Key Internal Business Processes Based on Critical Success Factors: A Case Study in Furniture Industry". *Business Process Management Journal.* Vol. 13, No. 1. January: 5.

Quesada-Pineda H. and R. Gazo. 2007. "Best Manufacturing Practices and Their Linkage to Top-Performing Companies in the U.S. Furniture Industry". *Benchmarking.* Vol. 14, No. 2. March: 211-221.

Raisinghani M.S., H. Ette, R. Pierce, G. Cannon, and P. Daripaly. 2005. "Six Sigma: Concepts, Tools, and Applications". *Industrial Management and Data Systems.* Vol. 105, No. 3/4. March: 491-505.

Remenyi D.W.B., A. Money, and E. Swartz. 1998. "Doing Research in Business and Management". *Sage Publications.* 1st Edition. London, United Kingdom.

Riadh A., R. Beauregard, and S. D'Amours. 2009. "Exploratory Case Studies on Manufacturing Agility in the Furniture Industry". *Management Research News. Vol.* 32, No. 5. May: 424-439.

Robinson S.. 1993. "The Application of Computer Simulation in Manufacturing". Integrated *Manufacturing Systems*. Vol. 4, No. 4: 18-23.

Ruddell S. and J.A. Stevens. 1998. "The Adoption of ISO 9000, ISO 14001, and the Demand for Certified Wood Products in the Business and Institutional Furniture Industry". *Forest Products Journal.* Vol. 48, No. 3. March: 19-26.

Russell R.S. and B.W. Taylor. 1999. “Operations Management”. *Prentice-Hall*. 2nd Edition. Upper Saddle River, NJ (U.S.A.).

San J.T.S.. 2000. “Applying Cost of Quality to Total Quality Management”. *International Conference on Quality Improvement.* Pakistan Institute of Quality Control: 117.

Sankar N.R. and B. S Prabhu. 2001. “Modified Approach for Prioritization of Failures in a System Failure Mode and Effects Analysis”. *The International Journal of Quality and Reliability Management*. Vol.18, No. 3. January: 324-335.

Santori P.R. and A.D. Anderson. 1987. “Manufacturing Performance in the 1990s: Measuring for Excellence”. *Journal of Accountancy*. Vol. 164, No. 5: 141-7.

Saunders M., P. Lewis, and A. Thornhill. 2003, .”Research Methods for Business Students”. *Pearson Education Limited*, 3rd Edition, United Kingdom.

Sayles L. and G. Straus. 1966. “Human Behaviour in Organizations”. *Prentice Hall*. London (United Kingdom).

Schaffer R.S. and H.A. Thomson. 1992. “Successful Change Programs Begin with Results”. *Harvard Business Review*. January–February: 80–89.

Schein E.H.. 1996. “Three Cultures of Management: the Key to Organizational Learning”. *Sloan Management Review.* Fall: 9–20.

Scholarios D.. 2005. “Research Methodology: Research Methods”. Unpublished Presentation. *Strathclyde Business School, University of Strathclyde*. Glasgow, United Kingdom.

Schuler A., R. Taylor, and P. Araman. 2001. “Competitiveness of U.S. Wood Furniture Manufcturers”. *Forest Products Journal.* Vol. 51, No. 7/8. July: 14-20.

Seth D. and V. Gupta. 2005. “Application of Value Stream Mapping for Lean Operations and Cycle Time Reduction: an Indian Case Study”. *Production Planning and Control (PPC).* Vol. 16, No. 1: 44-59.

Seth D., N. Seth and D. Goel. 2008. “Application of Value Stream Mapping (VSM) for Minimization of Wastes in the Processing Side of Supply Chain of Cottonseed Oil Industry in Indian Context”. *Journal of Manufacturing Technology Management*. Vol. 19, No. 4: 529-50.

Shahin A. and M.A. Mahbod. 2007. “Prioritization of Key Performance Indicators: An Integration of Analytical Hierarchy Process and Goal Setting”*. International Journal of Productivity and Performance Management.* Vol. 56, No. 3. April: 226-240.

Shahin A.. 2004. “Integration of FMEA and the Kano Model: An Exploratory Examination”. *The International Journal of Quality and Reliability Management.* Vol. 21, No. 6/7. July: 731-746.

Shillito L.. 1994. “Advanced QFD Linking Technology to Market and Company Needs”. *John Wiley & Sons, Inc*. New York, NY (U.S.A.).

Sim K.L.. 2001. “An Empirical Examination of Successive Incremental Improvement Techniques and Investment in Manufacturing Technology”. *International Journal of Operations and Production Management*. Vol. 21, No. 3. January: 373-399.

Sinclair D. and M. Zairi. 1995. “Effective Process Management through Performance Measurement. Part I: Applications of Total Quality-Based Performance Measurement.” *Business Process Re-engineering & Management Journal.* Vol. 1, No. 1: 75-88.

Sinclair D. and M. Zairi. 1995. “Effective Process Management through Performance Measurement. Part III: An Integrated Model of Total Quality-Based Performance Measurement”. *Business Process Re-engineering & Management Journal*. Vol. 1, No. 3: 50-65.

Skinner W.. 1986. “The Productivity Paradox”. *Harvard Business Review*, July-August: 55-9.

Snell S.A. and J.W. Dean. 1992. “Integrated Manufacturing and Human Resource Management: a Human Capital Perspective”. *Academy of Management Journal*. Vol. 35: 467-504.

Sukthomya W. and J.D.T. Tannock. 2005. “Taguchi Experimental Design for Manufacturing Process Optimisation Using Historical Data and a Neural Network Process Model”. *The International Journal of Quality and Reliability Management*. ABI/INFORM Global. Vol. 22, No. 4/5: 485-502.

Sullivan L.P.. 1986. “Quality Function Deployment”. *Quality Progress*. Vol. 19, No.1: 39-50.

Swinehart K.D., P.E. Miller, and C. Hiranyavasit. 2000. “World Class Manufacturing: Strategies for Continuous Improvement”. *Business Forum*. Vol. 25, No. ½. January: 19-28.

Taj S. and L. Berro. 2006. “Application of Constrained Management and Lean Manufacturing in Developing Best Practices for Productivity Improvement in an Auto-Assembly Plant”. *International Journal of Productivity and Performance Management*. Vol. 55, No. ¾. April: 332-345.

Takezawa N. and M. Takahashi. 1990. “Quality deployment and reliability deployment. In Akao, Y. (Ed.) Quality Function Deployment, Integrating Customer Requirements into Product Design”. *Productivity Press.* English translation. Chapter 7: 180-210.

Tammela I., A.G. Canen, and P. Helo. 2008. “Time-Based Competition and Multiculturalism: A Comparative Approach to the Brazilian, Danish and Finnish Furniture Industries”. *Management Decision.* Vol. 46, No. 3. March: 349-364.

Tapping D. and T. Shuker. 2003. “Value Stream Management for the Lean Office”. *Productivity Press*. New York, NY (U.S.A.).

Te-King C. and S. Chao-Ton. 2003. “Using the QFD Concept to Resolve Customer Satisfaction Strategy Decisions”. *International Journal of Quality & Reliability Management.* Vol. 20, No. 3: 345-359.

Teng S.H. and S.Y. Ho. 1996. “Failure Mode and Effects Analysis: An Integrated Approach for Product Design and Process Control”. *The International Journal of Quality and Reliability Management*. Vol. 13, No. 5. January: 8-26.

Teng S.H., S.Y. Ho, D. Shumar, and P.C. Liu. 2006. “Implementing FMEA in a Collaborative Supply Chain Environment”. *The International Journal of Quality and Reliability Management* . Vol. 23, No. 2/3. February: 179-196.

Terziovski M. and D. Samson. 1999. “The Link Between Total Quality Management Practice and Organizational Performance”. *International Journal of Quality and Reliability Management*. Vol. 16, No. 3: 226-37.

Thawesaengskulthai N. and J.D.T. Tannock. 2008. “Pay-off Selection Criteria for Quality and Improvement Initiatives”. *The International Journal of Quality and Reliability Management*. Vol. 25, No. 4. May: 366-382.

Thomson N..1995. “Simulations in Manufacturing Systems”. *J. Wiley and Sons*. New York, NY (U.S.A.).

Toppinen A., R. Toivonen, A. Mutanen, V. Goltsev, and N. Tatti. 2007. “Sources of Competitive Advantage in Woodworking Firms of Northwest Russia”. *International Journal of Emerging Markets.* Vol. 2, No. 4. October: 383-394.

Töremen F., M. Karakus, and T. Yasan. 2009. “Total quality management practices in Turkish primary schools*”. Quality Assurance in Education*. Vol. 17, No. 1: 30-44.

Tranfield D., I. Parry, S. Wilson, S. Smith, and M. Foster. 1999. "Teamworking: Redesigning the Organization for Manufacturing Improvements". *Technology Analysis and Strategic Management.* ABI/INFORM Global. Vol. 11, No. 2. June: 143-158.

Turner, T. J., U.S. Bititci, and S.S. Nudurupati. 2005. "Implementation and Impact of Performance Measures in Two SMEs in Central Scotland". *Production Planning and Control.* Vol. 16, No. 2. March: 135-151.

Tzelepis D., K. Tsekouras, D. Skuras, and E. Dimara. 2006. "The Effects of ISO 9001 on Firms' Productive Efficiency". *International Journal of Operations and Production Management.* Vol. 26, No. 10. October: 1146-1165.

Vandenbrande W.W.. 1998. "How to Use FMEA to Reduce the Size of Your Quality Toolbox". *Quality Progress*. Vol. 31, No. 11: 97-100.

Vickery S.K., C.L.M. Droge, J.M. Yeomans, and R.E. Markland. 1995. "Time-Based Competition in the Furniture Industry". *Production and Inventory Management Journal.* Vol. 36, No. 4. October: 14.

Voelkel J.G. and C. Chapman. 2003. "Value Stream Mapping". *Quality Progress*. Vol. 25, No. 5: 65-8.

Vokurka R.J., and R. Davis. 1996. "Quality Improvement Implementation: A Case Study in Manufacturing Scrap Reduction". *A Production and Inventory Management Journal*. ABI/INFORM Global. Vol. 37, No. 3. Third Quarter: 63-68.

Vokurka R.J., S. O'Leary-Kelly, and B. Flores. 1998. "Approaches to Manufacturing Improvement: Use and Performance Implications". *Production and Inventory Management Journal.* Vol. 39, No. 2. April: 42-48.

Vonderembse M. A. and T.S Raghunathan. 1997. "Quality Function Deployment's Impact on Product Development". *International Journal of Quality Science*. Vol. 2, No. 4: 253-271.

Waddell D. and S. Sohal. 1998. "Resistance: A Constructive Tool for Change Management". *Management Decision*. Vol. 36, No. 8: 543–548.

Walsh G.. 2005. "Multivariate Research Design". Unpublished Presentation. *Strathclyde Business School, University of Strathclyde*. Glasgow, United Kingdom.

Webber J.. 1990. "FMEA: Quality Assurance Methodology". *Industrial Management and Data Systems*. Vol. 90, No. 7. January: 21-23.

Westphal J.D., R. Gulati, and S.M. Shortell. 1997. "Customization or Conformity?" An institutional and network perspective on the content and consequences of TQM adoption. *Administrative Science Quarterly*. Vol. 42: 366-394.

Wheelwright S.C., and K. Clark. 1992. "Revolutionising Product Development". *Free Press*. New York, NY (U.S.A.).

White G.P.. 1996. "A Survey and Taxonomy of Strategy-Related Performance Measures for Manufacturing". *International Journal of Operations & Production Management.* Vol. 16, No. 3. January: 42-61.

Wilshaw G. and B. Dale. 1990. "Hilti Sells Total Quality". 3rd International Conference on Total Quality Management, IFS Conferences. *The TQM Magazine.* Vol. 2 Iss. 5, October, MCB UP ltd. United Kingdom.

Wilson J.P., M.A.T. Walsh, and K. LaScola Needy. 2003. "An Examination of the Economic Benefits of ISO 9000 and the Baldrige Award to Manufacturing Firms". *Engineering Management Journal*. Vol.15, No. 4. December: 3-10.

Withers B.E., M. Ebrahimpour, and N. Hitmet. 1997. "An Exploration of the Impact of TQM and JIT on ISO 9000 Registered Companies". *International Journal of Production Economics*. Vol. 53: 209-216.

Womack J., D.T. Jones, and D. Roons .1990. “The Machine that Changed the World”. Macmillan. New York, NY (U.S.A.).

Yin R.K.. 1994. “Case Study Research: Design Methods”. *Sage Publications* (171). 2nd Edition. London, United Kingdom.

Yin R.K. 2003(a). “Applications of Case Study Research”. Second Edition. *Applied Social Research Methods Series*, Vol. 34. Thousand Oaks, CA (U.S.A.): Sage Publications, Inc.

Yin R.K.. 2003(b). “Case Study Research Design and Methods”. Third Edition. *Applied Social Research Methods Series*, Vol. 5. Thousand Oaks, CA (U.S.A.): Sage Publications, Inc.

Yurdakul M.. 2002. “Measuring a Manufacturing System's Performance Using Saaty's System with Feedback Approach”. *Integrated Manufacturing Systems*. Vol. 13, No. 1: January: 25.

Yusof S.M. and E. Aspinwall. 2000. “Total Quality Management Implementation Frameworks: Comparison and Review”. *Total Quality Management*. Vol. 11, No. 3: 281-294.

Zantek P.F., G.P. Wright, and R.D. Plant. 2002. “Process and Product Improvement in Manufacturing Systems with Correlated Stages”. *Management Science.* ABI/INFORM Global. Vol. 48, No. 5. May: 591-605.

Zhang Q., M.A. Vonderembse, and M. Cao. 2006. “Achieving Flexible Manufacturing Competence: The Roles of Advanced Manufacturing Technology and Operations Improvement Practices”. *International Journal of Operations and Production Management*. Vol. 26, No. 6. January: 580-599.

STANDARDS

Chrysler Corporation, Ford Motor Company, and General Motors Corporation. (1995), *Potential Failure Mode and Effect Analysis (FMEA) Reference Manual.* 2nd Edition.

The American Supplier Institute (ASI). (1989). *Quality Function Deployment Implementation Manual*. Dearborn, MI (U.S.A.). http://www.amsup.com. Accessed January 2008.

The Failure Mode and Effect Analysis (FMEA) Info Centre (2007). U.S.A.. http://www.fmeainfocentre.com. Accessed June 2008.

The International Organisation for Standardisation (ISO). (2005). *ISO 9000:2000 Quality Management Systems - Fundamentals and Vocabulary*. Geneva (Switzerland). http://www.iso.org. Accessed February 2007.

The Quality Function Deployment (QFD) Institute. (2007). Ann Arbor, MI (U.S.A.). http://www.qfdi.org. Accessed January 2008.

The Society of Automotive Engineers. (1993). *The FMECA Process in the Concurrent Engineering (CE) Environment.* Aerospace Information Report AIR 4845. http://www.sae.org. Accessed July 2008.

10 Bibliography

BOOKS

Currie R.M., ed. 1977. Revised by R.M. Currie and J.E. Faraday. *Work Study*. 4th Edition. Pitman Publishing Ltd. Bath, United Kingdom.

Koenig Daniel T., ed. 2007. *Manufacturing Engineering: Principles for Optimization*. 3rd Edition ASME Press, New York, NY (U.S.A.)

Moore Ron, ed. 2006. *Selecting the Right Manufacturing Tools: What Tool? When?* Butterworth-Heinemann, Elsevier Imprint, Burlington, MA (U.S.A.)

Rhyder Robert F. and Dekker Marcel, Inc., eds. 1997. *Manufacturing Process Design and Optimization*, Monticello, NY (U.S.A.)

Rother Mike and Shook John, ed. 1999. *Learning to See: Value Stream Mapping to Create Value and Eliminate Muda.* The Lean Enterprise Institute. Cambridge, MA (U.S.A.).

Shiba, Shoji, Graham, Alan and Walden, David, eds. 1993. *A New American TQM: Four Practical Revolutions in Management*. Productivity Press, Portland, OR (U.S.A.)

Suri Rajan, ed. 1998. *Quick Response Manufacturing: A Companywide Approach to Reducing Lead Times.* Productivity Press, New York (U.S.A.).

DISSERTATIONS

Ates Aylin. “Strategy Process in Manufacturing SMEs”. PhD diss., Department of Design, Manufacture and Engineering Management, University of Strathclyde, Glasgow (United Kingdom), 2008.

Giles David. “Aligning Manufacturing Strategy with Business Strategy”. MPhil diss., Department of Design, Manufacture and Engineering Management, University of Strathclyde, Glasgow (United Kingdom), 2008.

PAPERS

Eden C. and C. Huxham, 2006. “Researching Organizations Using Action Research”. *Handbook of Organization Studies (Clegg S., Hardy C., Nord W., and Lawrence T., 2006 - Sage Publications, Beverly Hills - Second Edition, 2006).* University of Strathclyde Graduate School of Business, Glasgow (United Kingdom).

Eden C. and C. Huxham, 1996. “Action Research for Management Research”. *British Journal of Management,* Vol.7, 75-86. British Academy of Management (United Kingdom).

Suri R., 2003. “QRM and POLCA: A Winning Combination for Manufacturing Enterprises in the 21st Century”. *Technical Report, Center for Quick Response Manufacturing,* University of Wisconsin, Madison (U.S.A.): May.