"ZERO-DEFECTS PLUG AND PLAY"

General Quality Frameworks and Processes for Achieving and Maintaining High Levels of Delivered Product Quality in Computer Manufacturing

[1]

Jorgen Thelin

March 1993

[1] *This dissertation was originally submitted in part-fulfilment of the requirements for the Degree of Master of Business Administration of the University of Warwick, UK.*

MANAGEMENT SUMMARY

This dissertation describes the design of the overall quality framework and processes for use in ICL's Ashton Manufacturing plant.

It provides a set of generic processes to address the requirement of achieving and maintaining high levels of delivered product quality in a typical high throughput / high mix computer-manufacturing environment.

These frameworks are suitably general purpose to be applicable to any similar "world class" manufacturing situation with little alteration.

The dissertation outlines the two elements of manufacturing quality, namely conformance (no deviations), and removal of infant mortalities.

It shows how Delivered Quality Audits are a key method of assessing the true level of conformance of products shipped to customers, and also of gauging the customer's opinion of total perceived quality.

It emphasises the fact the manufacturing must now be regarded as a "knowledge-based" business, where knowledge retention is key to the on-going success of the operation. This is particularly true when viewed against the "fundamental economics of manufacturing", namely the constant need to contain and reduce overhead costs, and which in a climate of recession almost invariably leads to the departure of the oldest and most experienced staff, with a consequent loss of their accumulated knowledge and experiences.

The quality processes themselves are shown as interrelated, and unified within a single overall generic framework. The framework is considered as one of the vehicles for obtaining "Loose/Tight fit", where best practice techniques can be prescribed and standardised across the varied product ranges, yet still allowing "customisation" of the generic frameworks to accommodate the beneficial differences of 'Plants within a Plant'

The key element of Quality Improvement embodied within the framework is shown to be the generic "corrective action loop", which is capable of handling any of the varied types of problem likely to be encountered within a manufacturing environment. The success of this quality improvement system is critically dependant on the involvement of operations staff and "correction at source".

The other key element is the recognition that quality processes and systems have inherent limits to their effectiveness. To be able to exceed these limits, a "breakthrough" or "quantum-leap" change is necessary. While the "breakthrough" activities are being formulated and undertaken to create wide-ranging beneficial change, it is important to

recognised that the "control" activities of management are vital to prevent unfavourable changes or reversion to the previous methods occurring.

The final key concept explored is the three dimensions of organisational management - accountability, responsibility and authority. The importance of organisational design to align these elements together and match them to the organisational unit boundaries is clear. Ultimately, organisational structure can have a large influence on the operation and effectiveness of the overall quality processes.

Contents List

Table of Contents

List of Figures

Abbreviations & Definitions

P&P	Plug and Play metric
MPV	Manufacturing Process Validation
PP	Process Proving
PT	Product Trial
RP	Route Proving
PVT	Product Validation Trial - the forerunner of the MPV.
DQA	Delivered Quality Audit
EOLA	End-of-Line Audit
OOBA	Out-of-Box Audit
LQS	[Ashton] Local Quality System - for Error logging and Reporting
MFCC	Manufacturing Fault Clearance & Control system
ASK	Ashton System KEL (Known Error Log) - for Expert System diagnosis on DRS6000 failures
PMS	Purchasing and Materials Supply department
NPI	New Product Introduction department
GR	General Release
PRC	Product Release Certificate
UKCS	ICL (UK) Customer Service Division
I&C	Installation & Commissioning
ICOR	"Installation & Commissioning Operations Room" - Manufacturing warranty handling system
CRISP	The ICL UK Customer Service Call logging system
CA	[Root Cause] Corrective Action
ZD	Zero Defects
ISO9000	Internationally recognised Quality System standard
BS5750	British Standard equivalent to ISO9000
BS6001	British Standard on sampling techniques
SPC	Statistical Process Control
SQC	Statistical Quality Control (another name for SPC)
dELTA	ICL's 'Kaizen' system for channelling "many small improvements"
OEM	Other Equipment Manufacturers
POS	Point-of-Sale [terminal equipment / cash till]
FMS	Flexible manufacturing systems
FMEA	Failure Mode and Effect Analysis technique
UL/CSA	Underwriters' Liability - Product liability insurance system for the United States market
BABT	UK Telecommunications product approval
Series 39	ICL's range of mainframe products
SX	The large mainframe in the Series 39 range
DX	The distributed mainframe in the Series 39 range
DRS6000	ICL's large UNIX server product
DRS3000	ICL's small UNIX server product
PONC	Price of Non-Conformance
Short-shipment	Item missing from the product contents or consignment received by a customer

Acknowledgements

Thanks are due to my current colleagues in the Quality Department at ICL Ashton Manufacturing - Jim Thomas, Mike Drury, Dave Preston and Paula Daniels, who have put up with my various absences during the writing of this dissertation, and have "held the fort" for me.

Special recognition goes to Mike Drury, who has successfully inducted me into the area of hardware reliability and testing methods, and has taught me everything I know in that field. Mike has also acted as a sounding board on many occasions for my latest ideas, and has helped me shape these thoughts into workable systems.

Neville Carr recruited me to ICL originally, and coached and developed me during my early days in the company. He is one of the great practitioners of the art of organisational design, and central to this is his fundamental concept of the three dimensions of organisational management - accountability, responsibility and authority.

Tony Adderley recruited me to ICL Manufacturing, and started off and nurtured most of the activities undertaken in this project. To him must go recognition for providing the vision of what this project was ultimately trying to achieve.

Roger Wynne acted as my MBA Project Supervisor for Warwick Business School, and as well as supplying academic guidance, also provided a very rapid turnaround of comments on my dissertation drafts, to allow the tight submission deadline to be achieved.

Finally, thanks are especially due to my wife, Linda, who has put up with my many late night studying and writing sessions while this dissertation was being prepared, and throughout the Distance Learning MBA course generally.

1.INTRODUCTION

ICL Manufacturing Division's Ashton (-under-Lyne) factory is the main source of ICL's indigenous products. The whole range of products is assembled there, from the large SX mainframes through the mid-range DRS6000, to the high-volume products such as PC's and Retail Point-of-Sale Tills.

The dissertation describes the changes that have been planned and made to the quality frameworks and processes within the Ashton factory over the last 12 months to support the vision of "Zero-Defects Plug & Play", and the underlying thinking and rationale behind these plans.

To fully understand the design of the quality framework, it is important to appreciate the history and culture of ICL as a whole, and the major changes in manufacturing at Ashton over the last few years, which will be discussed next in this chapter.

In the following chapters, the problem situation that prompted this project will be outlined, leading on to a description of the "Zero-Defects Plug & Play vision", and then a detailed discussion of the quality framework. Finally, the current status of the project is reviewed, with the lessons to be learned from the experiences, and future recommendations and further steps.

The author is one of the Quality Consultants in the Quality & Engineering Department within ICL Ashton Manufacturing, reporting to the Ashton Quality Manager.

1.1. ICL

1.1.1. History

ICL was formed in 1968 by merging the UK's leading indigenous computer suppliers - English Electric Computers and ICT.

In 1984, ICL was acquired by STC PLC to form one of Europe's leading communications and information systems groups.

At the end of November 1990, Fujitsu Limited invested in ICL by taking an 80% shareholding in the company, with STC (now owned by Northern Telecom of Canada) retaining a 20% shareholding. ICL operates as an autonomous company within the Fujitsu federation of companies.

In October 1991, ICL merged with Nokia Data, strengthening its European operations, and as a result has some 26,000 employees. It supplies computing hardware, applications software and services of all types, operating in over 70 countries world-wide.

ICL's vision is to be Europe's leading international information technology company.

1.1.2. Markets

ICL is a market-led organisation dedicated to meeting the requirements, world-wide, of users in four specific vertical markets - retail, financial services, manufacturing and public administration (central and local government, health and the utilities). In addition, specialist operations covering transport / travel have been established in Europe.

Europe is ICL's domestic market. ICL plans to be the leading supplier in its chosen markets in Europe in the 1990s. Corporate objectives are to increase turnover and market share, with prime focus on Europe, through a policy of acquisitions, mergers, joint ventures and partnerships which fit the business strategy.

It is ICL's policy to collaborate with other leaders in technology globally, and in pursuit of this strategy ICL has partnership agreements with companies in Europe, the United States of America and the Far East.

1.1.3. Organisation structure

Traditionally, ICL has been structured as a series of Product Development divisions, and a series of Sales divisions world-wide, with the Manufacturing and Supply units forming the link between the two areas, ie. manufacturing the products for the Development units for shipping to the Sales units.

During 1992, following the acquisition of Nokia Data, and culminating in an organisational announcement of 13 Jan 1993, the structure has been changing, as Divisions assume more responsibility for their own activities.

The structure now consists of a series of vertical market units, largely geographically grouped, but each with its own manufacturing and sourcing capability, centred around the three main business streams of :

- Industry Solutions
- Volume Products
- Services

Manufacturing

ICL's principal manufacturing activities are undertaken in Europe.

The company manufactures personal computers in Finland; terminals and peripherals in Sweden; UNIX systems in Denmark; and personal computers in Russia. It has a 40% shareholding in International Computers Indian Manufacture Ltd (ICIM), which assembles a range of ICL's computers.

In the UK, its two plants are at Ashton-Under-Lyne in Greater Manchester and at Kidsgrove near Stoke on Trent.

The Kidsgrove plant is responsible for manufacture of printed circuit boards for ICL systems.
The Ashton plant assembles and tests Series 39 corporate and distributed mainframe computers, including the very high-powered SX systems; DRS3000 and DRS6000 mid-range UNIX servers; and personal computers.

Both Plants make extensive use of just-in-time and flexible manufacturing techniques which help to raise the company's competitiveness and make it more responsive to market needs. ICL's advanced manufacturing facilities, particularly at Ashton, have been recognised through a number of awards.

Autonomous Business Divisions

During 1992, ICL has been moving away from centralised control, and giving all divisions autonomy to run their own business operations in the most appropriate fashion.

This allows individual units much greater decision making powers, and much more freedom over what they sell, and to whom.

It also raises the challenge for Manufacturing units that there are no longer any "guaranteed" internal markets for their production capacity. They must compete against other external sub-contract manufacturers to "win" the business.

These steps will be completed during 1993.

1.1.4. Quality history & culture

In 1986, ICL embarked upon its quality programme based on the work of Philip Crosby [Crosby, 1979] by putting a continuous quality improvement process into practice across the whole company, one not limited to the manufacturing function.

During 1990, ICL became the first IT company to achieve company-wide accreditation in the UK to the ISO9000 Quality Systems standard. In 1991, ICL began the process of achieving similar accreditation for all its operations outside the UK, with the aim of having every part of the company registered by the end of 1993.

Customer Care

As part of its ongoing quality improvement process towards understanding customers' requirements, in 1991 the company introduced the Customer Care programme. This has been developed with the objective of making ICL a household name for quality and customer satisfaction.

The focus of this initiative is to get everyone within the company thinking about how their actions affect the end customer, and what can be done to make ICL "an easier company to do business with".

This involved an extensive training programme, which yielded numerous suggestions for projects to improve the image presented to the customer, and making the company easier to do business with. These are now being implemented.

This training programme is being followed up with the implementation of the "dELTA" system, which is a suggestion and continuous improvement process based on the Japanese principle of 'Kaizen' (ie. many small improvements).

1.2. ICL Ashton Manufacturing

1.2.1. Background and History

ICL's Ashton Manufacturing Plant is built on a seven acre site, occupies 14,000 m^2 of production and office space and now employs around 450 staff.

The factory's prime function is to manufacture and test products on behalf of the marketing organisations. Ashton Manufacturing recognises that it has no inherent right to manufacture ICL products, and has to compete with external organisations to prove that it can produce the best quality product, at the time the marketing organisation require it, and at the least cost.

History

The Ashton factory was opened in 1979 as a final assembly and test facility for ICL mainframe products, which up until then had been manufactured at two locations in the Manchester area: West Gorton and Dukinfield.

In 1980 there were five manufacturing locations in the U.K., employing 3400 people. By 1985 this had been reduced to four locations employing 2600 people, a reflection of changes in technology and competitive pressures on the cost of products.

By 1989 manufacturing was concentrated on two sites in the UK: Kidsgrove in Staffordshire becoming the centre for printed circuit board manufacture and low volume networks products, and Ashton becoming the centre for volume products. The number of employees required reduced to 1700; - 630 of whom were at Ashton.

Flexibility - Changes towards World Class Manufacturing

Throughout its history, Ashton has seen dramatic changes.

In 1983, it was a single product factory dedicated to the assembly and test of the 2900 range of mainframes.

1984 saw the introduction of Series 39 Mainframes, which were the first fruits of ICL's collaboration with the Japanese computer manufacturer Fujitsu, who supplied (to ICL designs) chips for the Series 39 Level 30 Distributed Mainframe and the Central Processor Unit for the top end Level 80 mainframe. 1985 saw the customer launch of Series 39 and the commencement of its volume manufacture, in parallel with 2900 (which ceased production in 1987). Assembly and test of Series 39 Level 30 products was carried out on the new "Mercury" FMS line.

Mercury represented the first phase of the application of Flexible Manufacturing Systems (FMS) in Ashton. The flexibility of the Mercury line had been proven in 1985 by the transfer of the manufacture of the System 25 mini-computer from ICL's Letchworth factory in Hertfordshire.

The integration of System 25 into the Mercury line was a clear demonstration of its flexibility, and represented a further step in the evolution of Ashton as a multi product ('high throughput / high mix') facility. (There are currently 350 different products, with output ranging from office products to large mainframes. It is believed that Ashton is the only plant in Europe where such a diverse range of computer equipment is made in the same factory.)

The next major step in the evolutionary process was the commissioning in 1988 of the second major phase of FMS introduction - Project "Apollo" which created a flexible sub-assembly area served by Automated Guided Vehicles (AGVs). Control systems were also developed to facilitate this, also embracing cable forms and a dedicated sub assembly area for specific products.

The Quality Message

All these developments took place in parallel with a rigorous Quality training and awareness programme mentioned previously, which represented a major investment in ensuring that all employees strove to achieve "Right First Time" in everything they do, whether on the shop floor or in any of the many support activities which are essential in a complex operation like Ashton.

People

Another key aspect of the evolution and continued success of Ashton has been the "Investment in People" programme and the Harmonisation programme which has eliminated differences in employment conditions between hourly rated and (monthly paid) staff employees, thus ensuring that the use of a key resource, people, is maximised.

Management of materials

On products manufactured since 1985, over 90% of the product cost is represented by materials. Management of materials within Ashton is a key activity, to ensure that the right materials are in the right place at the right time in an environment where the manufacturing programme can change significantly from one month to the next.

This flexibility / control must be achieved with the minimum possible investment in inventory, supported by data accuracy.

Significant developments have taken place in the relationships with suppliers, who can be considered as part of the inventory chain.

Considerable efforts are made to ensure that suppliers' quality meets Ashton's requirements, and that they can satisfy the needs for 'Just-in-time' deliveries.

Competitive costs

The dramatic changes seen in Ashton since 1985 have been a major factor in ensuring that ICL remains competitive in an increasingly tough market, as illustrated by recent financial results from major competitors in the world-wide computer industry.

To maintain this competitive position, ICL Manufacturing has an annual task to reduce product costs by 10% per annum.

Time to market

In an extremely competitive environment, with technological developments taking place at an increasingly rapid pace, the time taken to introduce a new product, from inception to delivery to customer, is a vital factor.

The improvement in timescales from the introduction of Series 39 (three years) to the DRS6000 Unix Processor launched in January 1990 (18 months) was partly achieved due to the support of Ashton staff over the product introduction period.

The ease with which DRS6000 was integrated into the Mercury line is further evidence of the flexibility of this unique facility.

1.2.2. Products

The range of computer products built on the site has increased over the years, such that now Ashton supplies a complete product range from the Series 39 mainframe processor (including the high powered SX system), the DRS6000 and DRS3000 Unix based mid-range systems, and several high volume Personal Computer & Retail products.

In reality, the manufacturing operations tend to be visualised and run as three main "product ranges":

* **Mainframes**

* **DRS6000 Mid-range Unix 'boxes'**

* **'High Volume' products**
  (PC's, DRS3000 "Unix PC's", Retail Point-of-Sale (POS) tills, terminals, and miscellaneous small communications and interconnect "boxes")

Within each main "product range", the working practices and key factors for success tend to be similar, and thus the differing requirements on the manufacturing processes tend to be grouped into these three product groups.

The volumes of each product produced each month of each type cover the whole of the volume spectrum, from tens of SX mainframe, through hundreds of mid-range DRS6000's, to thousands of 'High Volume' products.

Thus, Ashton clearly constitutes a "high throughput / high mix" manufacturing environment.

1.2.3. Awards

Ashton has performed an increasingly important role as a show-case for visits and tours to support the sales of ICL products and promote the company throughout the world.

The number of customer visits has increased from less than 50 in 1985 to over 200 in 1989 and exceeded 300 in 1990.

Numerous articles have appeared in the technical press on Ashton's implementation of Flexible Manufacturing Systems (FMS). Ashton has also featured in several key newspaper articles and media coverage has been extensive.

In 1989, Ashton was nominated as one of Britain's five best factories by "Management Today" magazine and consultants A.T.Kearney. At the presentation of the award, John Dickson, (Managing Director of ICL Product Operations) said:

> *"This award recognises the investments ICL has made in flexible manufacturing and just-in-time techniques which have elevated the Ashton plant into a show-case for world class manufacturing. It is also a tribute to the determined effort made by all our staff in Ashton to achieve the highest possible quality in the work we do and the computer systems we produce."*

The site is looked at as a benchmark and used by many other organisations from around the world.

Over 300 visits and events each year are tailored towards visitor's exact requirements, but the majority come to hear about:

- Total Quality Management.
- Ashton's success in material control and Just-in-Time techniques.
- The introduction of Flexible Manufacturing Systems.
- The workings of the 'Investment in People' initiative.

Visitors range across the whole spectrum of commerce and industry, to universities and schools.

External Awards

Ashton has received a number of awards in recognition of its quality achievements. To date, these are as follows:

1989 BEST FACTORY AWARD
Ashton was awarded one of the five awards made to British manufacturing companies by Management Today and consultants A.T.Kearney.

1990 BRITISH QUALITY AWARD
Ashton was awarded one of the three awards made by the British Quality Association.

1992 MICHELIN AWARD FOR QUALITY CIRCLE EXCELLENCE
The Vendor Quality unit was awarded this award for their Quality Improvement and Quality Circle activities.

External Quality Registration

In 1988, Ashton achieved registration against BS5750 Part 2 / ISO9002, the internationally recognised external quality systems standard.

1.2.4. Organisational structure

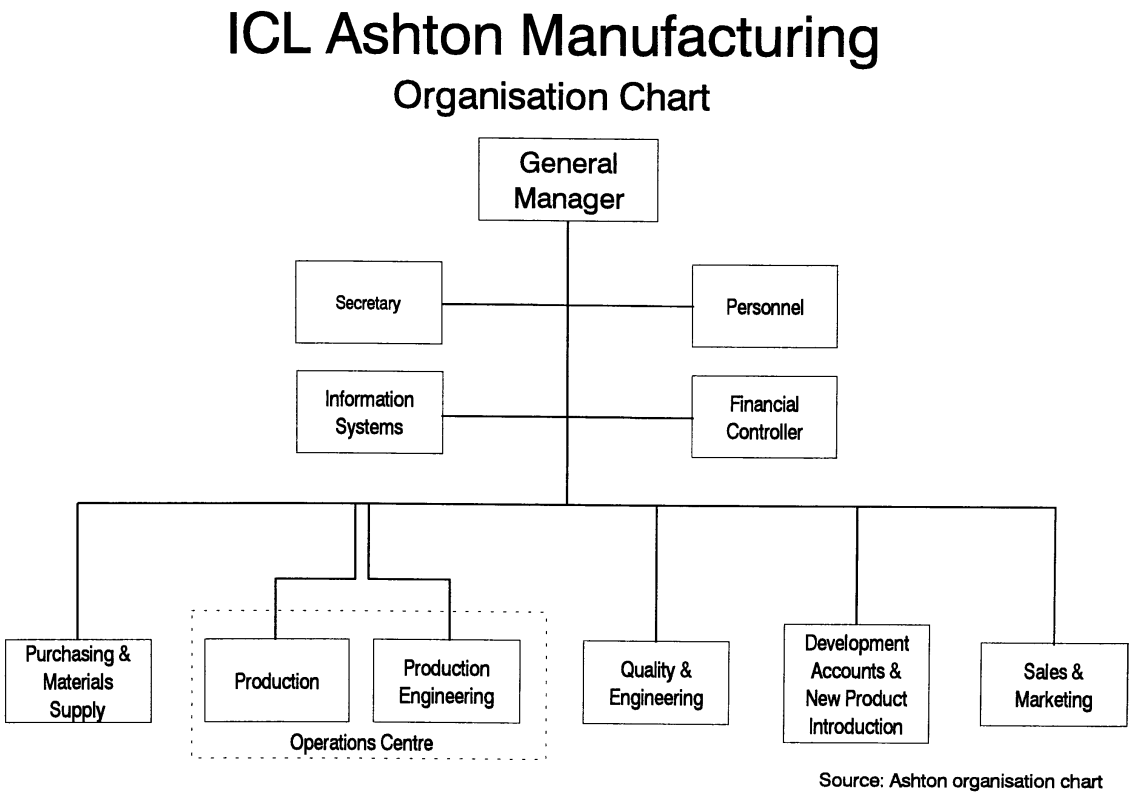

Figure 1 - Ashton Manufacturing Top level Organisational diagram

There are five main areas of operation and these are:-

Line Production Operations

Directly responsible for assembling and testing the products, against a required programme of customer orders. Flexible manufacturing techniques are used that ensure best use of manufacturing resource, with the assembly and test operatives being trained and hence, flexible, across a wide range of jobs.

Purchasing & Materials Supply

Well over 95% of the costs at Ashton are in materials supply to the factory.

Purchasing & Materials Supply (PMS) ensure that materials are supplied directly from the vendor to where it is needed on the shopfloor.

Just-In-Time (JIT) principles are used throughout which has enabled considerable savings and inventory costs since the systems were introduced in 1985 by enabling improvement in the stock turns from five in 1985 to over twenty one in 1991.

New Product Introduction

This department is responsible for managing the introduction of new products into the factory.

They take a new product from the design stage through prototype to the final assembly programme.

Manufacturing Engineering

Manufacturing Engineering are the interface between Product Introduction and the Line Production units.

They take prototype products and convert them into production models ensuring that tooling, suitable workstations and Operator work instructions are available in order to assemble the product efficiently. The workstations are designed as flexible manufacturing systems enabling many different products to be built in the same area. Up to 70% of floor area has been saved using this method.

Quality

As a result of the Quality Improvement Process (QIP) the Quality function has been largely devolved to the appropriate line areas leaving just a small central department. This is mainly concerned with auditing both the factory and vendors regarding quality processes, and guiding the factory in its conformance to external quality accreditation eg. BS5750, BABT [product approval], and UL/CSA [product liability insurance].

The main functions are supported by the Sales & Marketing, Site Services, Information Systems, Finance and Personnel departments.

1.2.5. Recent changes

During 1992, Ashton began the movement towards selling its manufacturing capability and capacity to OEM (Other Equipment Manufacturers) products and contract manufacture. These sales contracts are intended to generate external revenue to supplement the revenue from internal ICL units, and in this way allow wider sharing of the factory overheads, and cost reductions to be passed on to the internal transfer prices for ICL products.

To facilitate this new business orientation, the structure of the organisation within the factory has changed over the last 6 months to amalgamate the previous 3 separate Product Centres (one for each of the three main product groups described previously in section 1.2.2) to a single Production Operations Centre, with a separate Sales & Marketing department reporting directly to the factory General Manager, and with the Quality functions devolved to the relevant line units.

With the current recessionary economic climate, it was necessary to reduce staffing levels during this time, which occurred as two batches of voluntary and compulsory redundancies, one in August 1992, and the other in January 1993.

In November 1992, the General Manager was needed to take up a trouble-shooting role in another part of the company, and so departed at very short notice. The then Operations Centre manager was promoted to General Manager of the factory, with the units within the Operations Centre continuing to reporting directly to the factory manager.

Clearly, the Ashton factory has experienced a period of extreme turbulence and change over the last 6 months.

1.3. Quality at Ashton Manufacturing

1.3.1. Ashton's Quality History

The ICL Manufacturing Plant at Ashton is among the world leaders in terms of its use of advanced industrial practices, but one can understand its specific successes only in the context of a programme, launched in 1986, which has changed the face of the entire company: "Quality the ICL Way".

This programme offers a dynamic interpretation of 'Quality' philosophies and may be analysed in three distinct phases:

- Determination,
- Education,
- Implementation.

Determination

The determination, made in the first place by the Board and Chief Executive, manifested itself in a commitment of resources both in terms of people and money. Often companies - perhaps spurred on by misunderstanding Crosby's assurance that 'Quality is Free' [Crosby, 1979] - have declined to give their programmes the funding required to establish Quality practices.

Furthermore, ICL's Quality pioneers recognised that providing the resources would not be enough if their determination was not repeated at every level of the company.

At Ashton, every employee gave his or her personal commitment to the Quality programme, and the success of the programme in its early days at Ashton led the way for the rest of ICL.

Education

With both the personal and financial commitment already forthcoming, 'Quality the ICL Way" manifested itself in an education programme whose scale is best understood from a list of the number of people to go through courses.

Every single company employee (all 22,000 at that time) went through the general course, and nearly 1,500 went to take one of the further specialist courses. In excess of 100,000 man-days have now been invested in Quality education at ICL, and the company is justifiably proud to have won a British Training Award for the programme in 1988.

The subsequent year it again won an award for the Core Technical Training Programme, which ensures that education in Quality (and other technical subjects) is a continuing process.

Ashton has again played a vital part in this process. The Quality Team selected, and trained, their own people to be the Quality educators. As a result they could adapt the training material to Ashton's particular requirements.

Ashton's rapid incorporation of Quality standards led it to be the first site in the company to host a Zero Defects day.

Implementation

The consequence of the Education Programme was Total Quality Management throughout the company.

TQM is a methodology rather than a philosophy, and as a result, means a permanent change in the way that ICL is run.

In particular, it meant the implementation of a Corrective Action process whereby employees are able to identify and address the root causes of non conformance. (This process is currently being evolved into the "dELTA" continuous improvement process, as previously mentioned in section 1.1.4.)

This is a dramatic shift from depending on ad hoc "fixing" processes, and enables the employee to improve operations outside their specific work area.

As a result, the entire working process at ICL is continually under scrutiny, rather than existing only as a set of isolated, inflexible procedures.

Ashton extended these principles by setting up joint Corrective Action teams with other parts of the company.

Initial estimates in 1986 put the Price of Non Conformance (PONC) for the company at £160 million, but it had been reduced by £100 million three years later. PONC [Crosby, 1979] is the measurement by which the company continues to evaluate its operations.

The attainment of BS5750 registration demonstrated that there has been a concurrent improvement in the company's standards.

Both these factors show the impact of ICL's Quality commitment.

This impact may also be demonstrated by the number of people who have become involved in the management of the Quality programme. To date, over 750 people world-wide have been active in the Quality Improvement Teams which manage the Quality Improvement Process (QIP) and identify specific action in such areas as Measurement, Cost of Quality, awareness, recognition and (at a very early stage) education.

ICL's international growth is clearly due in no small part to its commitment to Quality. Ashton was one of the first areas of the company to adopt and implement 'Quality - The ICL Way' and became a role model for the rest of the company.

1.3.2. The Quality function's role

The Quality role is composed of two main types of activity:

- Strategy
- Operational

The strategic activities are performed by the Quality & Engineering department, and the three Quality consultants within that unit. These activities cover such items as defining the overall Quality framework, and top-level monitoring and diagnosis of process issues and systems.

The operational activities were previously performed by a centralised Quality department, but have been progressively devolved to the appropriate line units. These activities include detailed investigation of product problems in the factory or the field, return of failed items to vendors, and vendor liaison to improve in-feed quality.

1.3.3. Organisation & Responsibilities

The Quality function within Ashton Manufacturing is divided between several units:

Ashton Quality Manager

- Overall responsibility for all quality issues and processes within Ashton Manufacturing.
- Sign-off authority on Product Release Certificates (PRCs) for Manufacturing on all New Product Introductions.

Quality & Engineering Department

- Headed by the Ashton Quality Manager.
- The quality section contains three Quality Consultants plus one Assistant, who provide advice and guidance to other units on 'best practice' methods and techniques in the areas of process design, procedures & documentation, product reliability, metrics, fault analysis, external product liability approvals (eg. UL/CSA and BABT) and internal & external audits.
- Provide the overall Quality Strategy frameworks for the factory.
- Approval of Manufacturing Test Strategies for all New Product Introductions.
- Maintain a "watching-brief" over the factory's quality activities and systems.

Production Engineering Department

- Diagnosis of failing parts returned from the field.
- Performing root cause analysis on other problems reported by the field (such as missing items - Short Shipments) and identifying the corrective action necessary to prevent recurrence.
- Liaison with Line Production units to define and implement corrective actions.
- Performing all activities for the Manufacturing Process Validation (MPV), in conjunction with Line Production and New Product Introduction departments.

Vendor Quality Department

- Part of the Purchasing & Materials Supply Unit.
- Liaison with Suppliers on all parts failing within the factory or in the field.
- Monitoring overall supplier and bought-in part performance, to identify and investigate any trends or patterns.
- Providing assistance to suppliers with improving the 'delivered quality' into the factory of bought-in parts.

Line Production Units

- Analysis of field problems other than 'functional' part failures (which are handled by Production Engineering).
- Implementation of corrective actions to resolve field problems identified, in collaboration with Production Engineering.
- Performing pre-production builds and assembly audits as part of the Manufacturing Process Validations (MPVs).

As is apparent from the above list, there is considerable overlap among these functions and units. This encourages a collaboration approach to quality problems, but also can lead to diluted accountabilities, and hence lower performance.

As will be covered more fully later in the dissertation (section 6.8 - Organisational Structure), the problems inherent with this situation of the duplication and split of key quality responsibilities have become increasingly apparent throughout the duration of this project.

This chapter has provided an introduction to the ICL Ashton Manufacturing factory, and its situation within the ICL group of companies. The next chapter will investigate the problem symptoms that initiated the project described in this dissertation.

2. PROBLEM SYMPTOMS

2.1. Plug & Play problems

Plug & Play is the system Manufacturing use to provide a measure of defective output received by the customer.

The concept behind the metric is to measure the number of systems shipped that will "Plug-in and Go" first time without any problems.

A fuller discussion of the detailed mechanics and characteristics of this measure is included in a later section (5.1 - "Measure of Manufacturing Delivered Quality").

The latter part of 1991, and early 1992 saw a significant drop in the 'Plug & Play' metrics on both the main Ashton products - DRS6000 & SX mainframes. Also during this time period, the DX mainframe was introduced, and it also seemed to be suffering from low 'Plug & Play'.

Below are the metrics graphs that where the first symptoms of the problem:

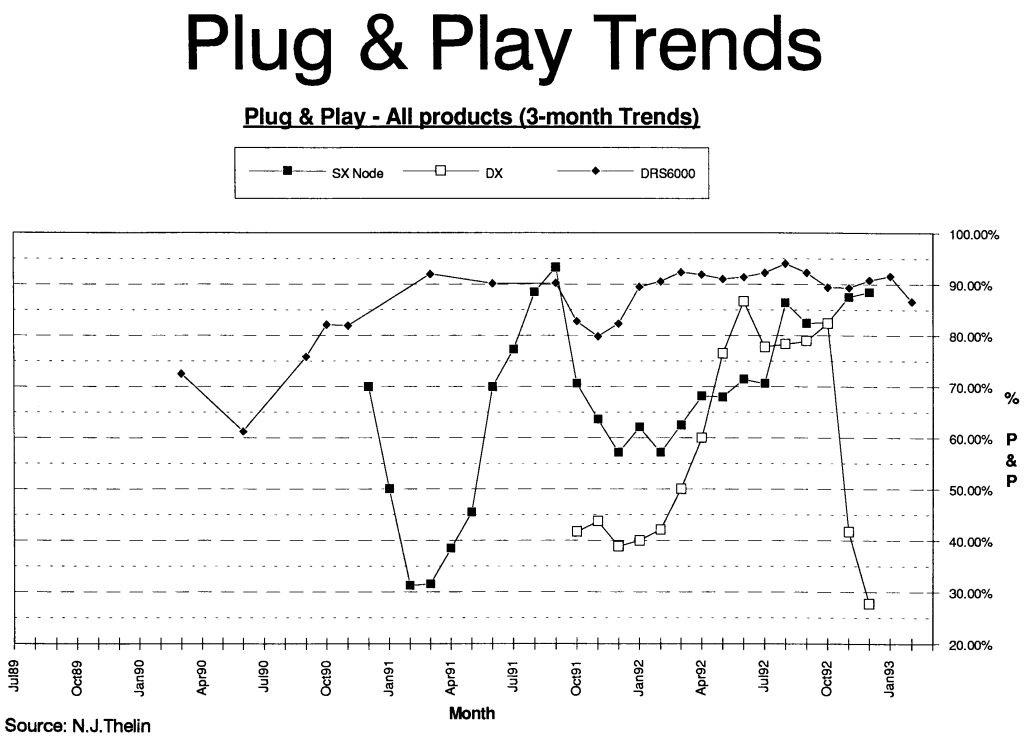

Figure 2 - Ashton Manufacturing Plug & Play Trend Graph

As can be seen, the problem started to become obvious in about September 1991.

Investigation of these failures, which result in warranty claims against Manufacturing, identified root causes for most problems that constituted design errors, requiring formal engineering changes. Thus the majority of fails were not attributable to Manufacturing liability or defects.

However, one key cause for concern from Manufacturing's point of view was the slowness in identifying these problems, and finding solutions with the Development group. This was partly caused by sluggishness of the Manufacturing diagnosis processes at investigating underlying root causes.

While the cut-in of these engineering changes within the factory did produce an increase in the Plug & Play metric, by April 1992 it was becoming apparent that the improving trend had largely flattened out into a "plateau", ie. further improvement was becoming extremely difficult to achieve.

This prompted a critical evaluation by the Ashton Quality department of the Plug & Play situation, including the metric itself.

2.1.1. Critique of the Plug & Play metric

The above situation highlighted a significant problem with the 'Plug and Play' (P&P) metric - namely that the real responsibility for many of the failures laid with the design group, even though the metric was seen as a measure of manufacturing performance.

Secondly, especially on the products that experience a high rate of design errors and engineering changes, it is impossible to get anywhere near the target performance that is set based on manufacturing's ability to produce a product that conforms to the design specification when that specification is itself not achievable due to inherent design errors.

This problem was compounded by the fact that the Plug & Play measure was based on the whole 28-day manufacturing warranty period, but most of this period actually constituted the early life of the product (often referred to as the "burn-in phase" [Oakland, 1989]), rather than a pure measure of the "Plug-in and Go" aim of manufacturing.
This situation distorts the P&P metric in the above case where most of the failures do not occur immediately, but occur within the early days of running the product, ie. constitute 'infant mortality' failures [O'Conner, 1985].

However, it remains one of two key quality tasks of a manufacturing plant to remove such infant mortality failures before shipment, primarily through soak testing and thermal stress testing (see section 4. "Manufacturing Quality Framework - Overview"). As the Development division specify and supply the testing to be performed on their products, such infant mortality fails are regarded as their responsibility, although manufacturing have a vested interest in assisting them in improving the screening processes.

Therefore, it was apparent in May 1992 that some method needed to be devised to focus on those problems that truly were manufacturing's responsibility. A new measure ('Defects per Installation') was devised to fulfil this objective, but also to try to capture the wider measure of problems involving non-functional fails (eg. items missing) which constitutes the other key quality concern for a manufacturing unit (see section 4. "Manufacturing Quality Framework - Overview").

2.1.2. Limit of current systems and processes?

Even once the design engineering changes were implemented, it was still proving very difficult to get the 'old' plug & play metric to exceed 95%

It was considered that this may represent some sort of fundamental "limit" imposed by our current quality systems and processes, as despite much effort to try to improve the Plug & Play situation, little impact was being felt.

It appeared that the current quality process could not remove the last "persistent" level of defects in their current forms. As Foo & Friedman emphasise:

> *"If a company uses only variability reduction to lower defect levels and fails to introduce innovations in a manufacturing process, the process will encounter 'sticking points', or quality thresholds. When these thresholds are reached, procedures that had previously maintained the current quality level can no longer improve the process significantly. At this point, only a fundamental change to the system (either in technology or methodology) will keep it from remaining stalled."*
>
> [Foo & Friedman, 1992]

This was pointing very clearly to the need for some radical review and overhaul of the underlying quality framework in use within the factory.

2.1.3. "Persistent" level of defects

Even after the improvement in the Plug & Play measure, this "persistent" level of defects meant that one in every 20 of our customers would have some sort of problem with machines produced by Ashton.

This was considered unacceptable, so it was decided that some step-change was required for further improvement, and some significant changes would need to be made to the quality systems in use within the factory to effect such a 'step change' in the effectiveness of the processes at removing and preventing the last defects.

Based on the previous Quality training and culture in the company, it was felt that the "vision" we had to keep in mind, and strive for, was "Zero Defects Plug and Play" based on Crosby [Crosby, 1979] (or "ZD Plug-in and Go" as it perhaps should be called, to distinguish from the 'old' Plug & Play measure which actually covers 'Manufacturing Warranty claims'. However, as the term 'Plug & Play' is widely recognised & used, the concept is typically referred to as "ZD P&P").

On the basis of this aim, the Ashton Quality department produced a discussion paper [Drury & Thelin, 1992] for the Managing Director of Manufacturing Division, to act as a feasibility study on whether Manufacturing can achieve zero defects on the Plug and Play quality measure at customer installation, and hence whether a target of zero fails could realistically be used. This discussion paper outlined the concepts of 'ZD P&P', and the consequences of reliability theory implicitly involved in such measures of installation effectiveness.

The specific contents of this document are described in the next chapter (3. "Zero-Defects Plug and Play"), as they are central to the whole thrust of this project.

2.2. Plug & Play on New Products

As is also apparent from the Plug & Play trend graphs (Fig 2), the Plug & Play on new products immediately after volume shipments commence starts low, then immediately drops, before slowly climbing to "reasonable" levels.

This immediately points to the fact that the Product Introduction processes used within Ashton to prepare the manufacturing operations for the 'ramp-up' to full production volumes are either not finding, or are not successfully removing, all of the problems with a new product before full volume shipments occur.

The initial shipments of new products are likely to be closely monitored and supervised by Engineers from the appropriate Development division, so allowing immediate on-site assistance to rectify any potential problems, so the first set of shipments may appear to experience slightly higher Plug & Play than they strictly did achieve. This is an example of the fact that the Plug & Play measure only counts failed parts that need replacement, but not those that could be "repaired" on-site through skilled engineer intervention. (See section 5.2 for a fuller description of the inherent problems with the Plug & Play measure.)

From this, it was also obvious that changes would be needed to the New Product Introduction processes used within Manufacturing, to provide a more complete screen for initial problems, and hence improve the "Plug-in and Go" ability of the products early in their lifecycle.

3.ZERO-DEFECTS PLUG & PLAY

This chapter shows the contents of the original discussion paper on "Zero-Defects Plug & Play" [Drury & Thelin, 1992], followed by the implications of that paper on this project.

3.1. ZD Plug & Play - Theory

Zero Defects Plug & Play (ZD P&P) is the level based on failures that would be expected to occur randomly as part of the "natural" reliability of the unit or system over the defined period of installation. This can be worked out from the predicted settled down reliability.

For example for a typical DRS6000, given a 24 hour period for installation, this works out as 5 fails per 1000 installations using the 1.9 fails per year/system target.

Being such a low level, in reality over any month a ZD target of no Installation and Commissioning (I&C) fails is realistic for a product such as DRS6000 with a suitably short installation period.

3.1.1. Method of achieving ZD P&P ?

To achieve "Zero-defects Plug and Play", the following measures are necessary:

a.	All "infant mortality" failures [O'Conner, 1985] should be found in production, prior to shipment from the factory.
b.	Induced failures (due to packing, transportation and installation) need to be identified (and eliminated).
c.	Failures resulting from excessive storage periods should be eliminated, or discounted from the Plug & Play measure.
d.	No 'short shipments' (missing or wrong items sent) should occur.

3.1.2. Infant Mortalities into Production

To bring all infant mortality failures from the Installation and Early Life period back into production the following is necessary:

a. Accurate monitoring of production / test processes to ensure failures seen in the test process occur as early as possible i.e. The last part of the test process needs to achieve zero fails if no installation fails are to occur.

b. Use of test processes that will cause early life failures to be induced during (and as early as possible in) the manufacturing cycle.
This is likely to involve stressing and elevated temperature testing.

c. Regression rules for production test need to be clearly defined such that no part of a system can leave the factory before having gone through the full test process without failure.

d. Discipline needs to be maintained throughout the test process, but especially during the later stages when pressure to ship will be most intense.

This needs to include :-

- Accurate and prompt data logging, in real time.
- Proper segregation of failed parts and PCB's immediately upon failure.
- Strict adherence to regression rules.

e. Investigation of failures needs to be prompt, specifically to address why the fault occurred, and what needs to be done to eliminate them, or bring them back into the factory and move them to an earlier stage of test.

Therefore, the priority for analysis needs to be:-

A. ALL installation fails.
B. ALL fails during the final stages of test.
C. Other failure types, as before.

The process needs to be such that quick turnaround & responsive feedback is provided for the high priority type of faults, with the aim of delivering real corrective actions and process changes.

3.1.3. Induced failures

1. It is vital to be able to distinguish the root cause of all induced failures.

2. Rapid investigation is required of the events that occurred on site during the installation process, so that the trail does not "go cold".

In particular the turnaround time on the diagnosis of boards that prove to be 'No Fault Found' (NFF) needs to support this.

3. Corrective actions / process changes need to be rapidly identified and implemented for all induced fails.

3.1.4. Storage

Long periods in storage between the end of manufacture and installation on site can have an adverse effect on plug and play.
Reliability theory recognises that failures can occur while products are in the dormant state (i.e. switched off). These dormant failure rates are very low compared with the operating failure rate. However they can still have a measurable impact on plug & play. (Based on limited literature on this subject the failures from a month in store could be equivalent to one to three days of operating).

Currently, Ashton are seen to be responsible for any failures at installation, even if the unit has been stored for a considerable time - up to 6 months.

The only way to ensure that this type of failure does not impact plug and play figures is to prevent long periods of storage, or discount those systems from the measures.

While storage involves more than the occasional one unit, ZD Plug and play is probably not achievable.

3.1.5. Short Shipments

Ashton's processes need to be sufficiently capable to guarantee that all parts required are shipped.

1. Place checkpoints into the process to trap short shipments earlier in the manufacturing cycle, and prevent them slipping through to later stages undetected.

   Prevention - Failure Mode & Effects Analysis (FMEA) investment
   ie. study the opportunities to do it right.

   Inspection / Action standards - eg. SPC, BS6001 to monitor fails.

2. Understand the root cause of the process deficiency that caused any short shipment to both happen in the first place, and not get found until after the product was output.

3. Eliminate the process deficiency that caused the short shipment in the first place.

Correction Integrity -	Vetted root cause corrective action plan and trialed solutions. A 'fix' not addressing the root cause is only a second choice.

3.1.6. Measures

Measures to support and monitor the progress towards Zero-Defects Plug and Play are:-

*	Number of Installation failures, with the target of effectively Zero (ie. no statistically significant deviation from zero).
*	Responsiveness of the diagnosis process for the critical failures (type (A) & (B) above), as time to deliver corrective action once the board is available to Ashton. (Measures the Efficiency of the diagnosis process)
*	Number of diagnoses that deliver real root cause corrective actions or process changes. (Measures the Effectiveness of the diagnosis process)

3.2. Implications of the ZD P&P discussion paper

A colleague (Mike Drury - ICL's recognised expert on reliability) was already looking at the requirement to improve the in-house screening and testing processes, with some considerable success.

The other key implication from this investigation was the fact that the 28 day Installation warranty period coupled with the inherent reliability characteristics of the machine designs meant that Zero Defects was impossible when this whole warranty period was considered, due to the cumulative probability of random failures during this period (the bottom of the reliability 'Bathtub' curve [O'Conner, 1985]).

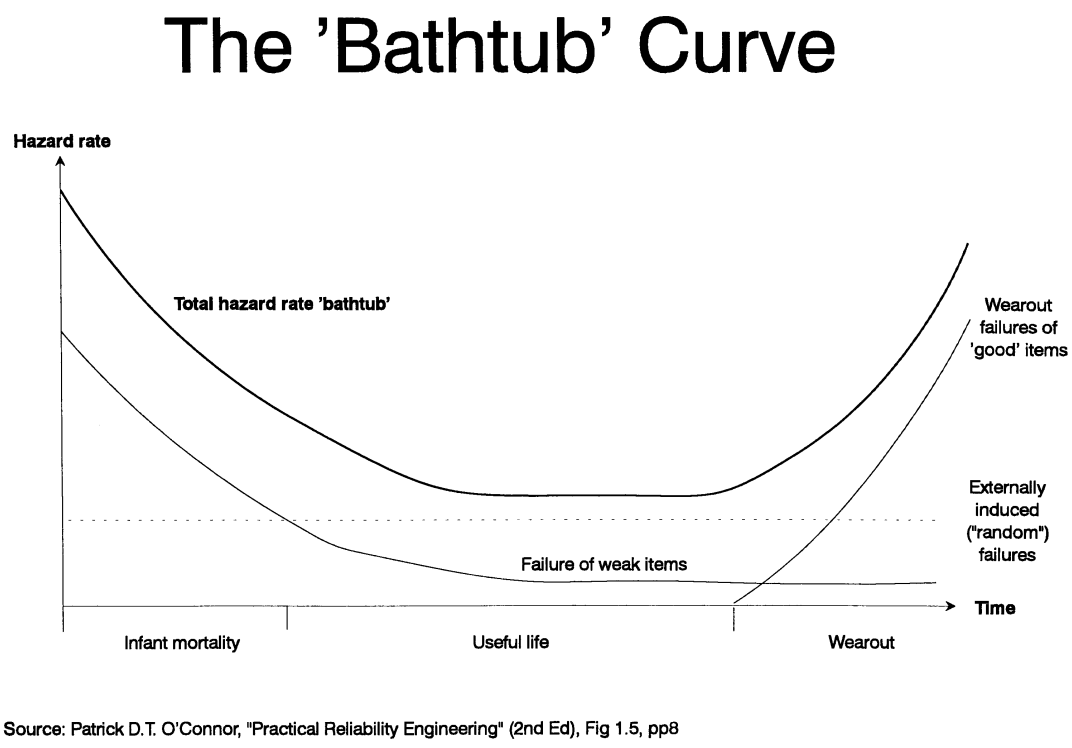

Figure 3 - The 'Bathtub' Reliability Curve

This, again, reinforced the need to focus the "Installability" measure on the time up to the end of installation, which constituted a sufficiently short timescale that random failures would have little impact.

In this way, it would be possible for manufacturing to focus very specifically on the problems it was directly responsible for, or should be removing from the product before shipment.

Because the number of failures in this group should be much smaller, due to the fact that most of the 'early life' design problems would not be included, the real issues that manufacturing needed to address would be highlighted more clearly, and could be dealt with effectively.

As a result, it was decided to implement the "Defects per Installation" measure as the Ashton "Installability" metric, and some key changes to the internal quality processes would be required to support this and enable Ashton to realistically aim for a target of zero fails.

The next chapter will provide an overview description of the quality framework to be implemented, with chapter 6 providing a more detailed discussion of each of the key elements within that framework.

4.MANUFACTURING QUALITY FRAMEWORK - OVERVIEW

4.1. Manufacturing Quality

Macbeth has stated the Manufacturing Deliverables as:

1. Quality,
2. Delivery,
3. Cost,

with quality being "the underpinning construct of the whole of manufacturing [Macbeth, 1989].

Within the above Quality deliverable, Garvin has identified eight dimensions of product quality [Garvin, 1984]:

1. Performance,
2. Features,
3. Reliability,
4. Conformance,
5. Durability,
6. Serviceability,
7. Aesthetics,
8. Perceived quality

Of these dimensions, the majority are determined by the design of the products, and as Macbeth points out, "any quality lost at design cannot be put back at any other stage in manufacture" [Macbeth, 1989].

Hence, from a manufacturing point of view, product quality on most of these dimensions are "givens" which cannot be altered, and so are therefore irrelevant to the Manufacturing organisation.

This leaves the two key quality attributes that the computer manufacturing organisation is tasked with delivering, namely:

A. **Conformance**

Conformance to specification, with no deviations ("Zero Defects", as Crosby has termed it [Crosby, 1979])

B. **Reliability**

While the overall reliability of a product is determined by it's design, Manufacturing is charged with the key task of removing all Infant Mortality fails (failures of weak items) before the product is shipped to the customer, so that early-life failures are minimised, and the field reliability is determined solely by the "random" fail rate at the bottom of the 'Bathtub' curve [O'Conner, 1985].

These are what Schonberger describes as the two overriding goals of World Class Manufacturing [Schonberger, 1986], ie.

* Reduction of deviation

  (= conformance)

* Reduction of variability

  (= reliability -> being on the flat bottom of the 'Bathtub' curve;
  as well as the Delivery element of manufacturing [demand lead time])

The actions necessary to improve testing methods, in order to more successfully induce the early-life infant mortality failures in-house before shipment will not be considered in this dissertation, as that is outside the scope of this specific project, and is a highly complex subject in itself. A useful discussion of the topic, for those interested, is provided by [Parker & Harrison, 1992].

This dissertation will be focusing on the topic of increasing the conformance dimension of delivered product quality, and in particular the quality processes required to obtain conforming and capable end-to-end manufacturing processes delivering consistent output.

The overall objective of the quality frameworks described in this dissertation, therefore, is to **improve the delivered quality of manufactured products**, but in particular this boils down to:

1) Reducing the number of defects attributable to manufacturing that are delivered to customers.

2) Trapping more errors in-house

3) Pushing errors back in the process for correction at source"

The discussions, will be taking a "high-level" view of the manufacturing activities, and will be based on the following generic manufacturing process:

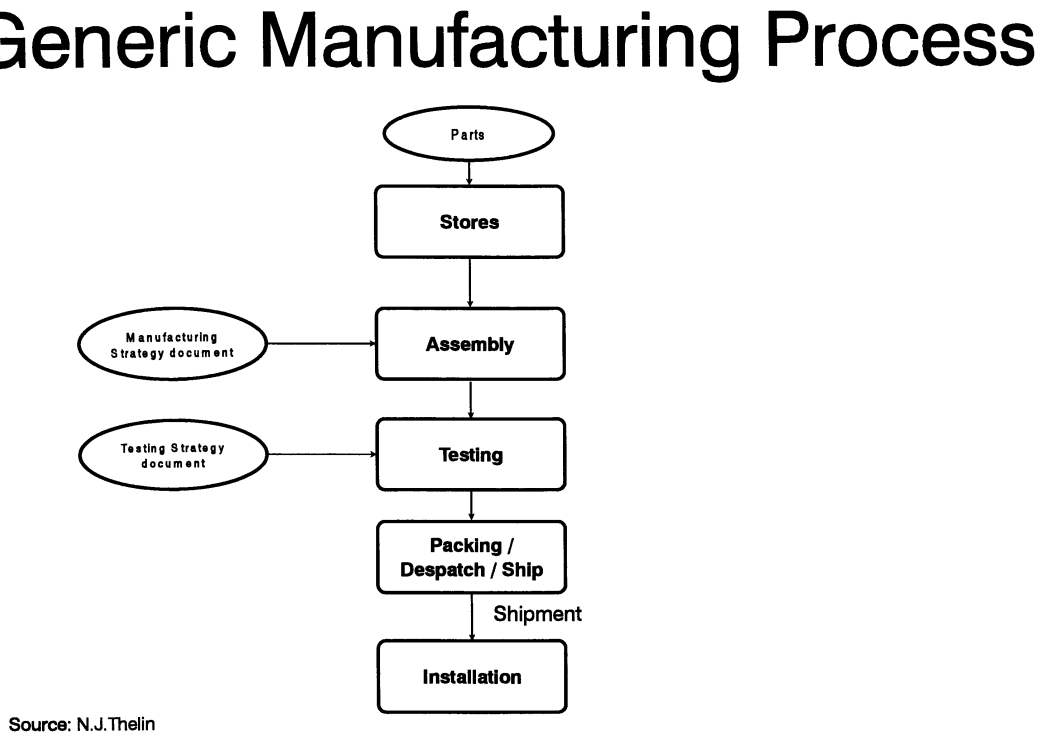

Figure 4 - The Generic Manufacturing Process

The key principles that are central to the quality systems or changes necessary are:

- Prevention
- Involvement
- Process proving

In particular, many of the activities outlined involve "up-front" actions to prove new products or manufacturing processes, which obviously require a greater initial investment of time in preparation and planning before the final implementation of the process or release of the product.

However, as Macbeth emphasises, this approach is typical of the Japanese, and leads to quicker implementation and a reduced total elapsed time overall, compared with the "Western" approach [Macbeth, 1989]. In particular, choices are more unconstrained early on. As time elapses, earlier decisions and commitments begin to reduce freedom as well as making any required changes more difficult to effect and therefore more costly.

This is especially true during the introduction of a new product involving the move from pilot production builds to full volume production operations.

4.2. Overall Framework

The overall framework is made up of five key elements, which are summarised below, immediately after a diagram showing how all these elements fit together. In the next chapter, each of the individual elements is covered in greater detail.

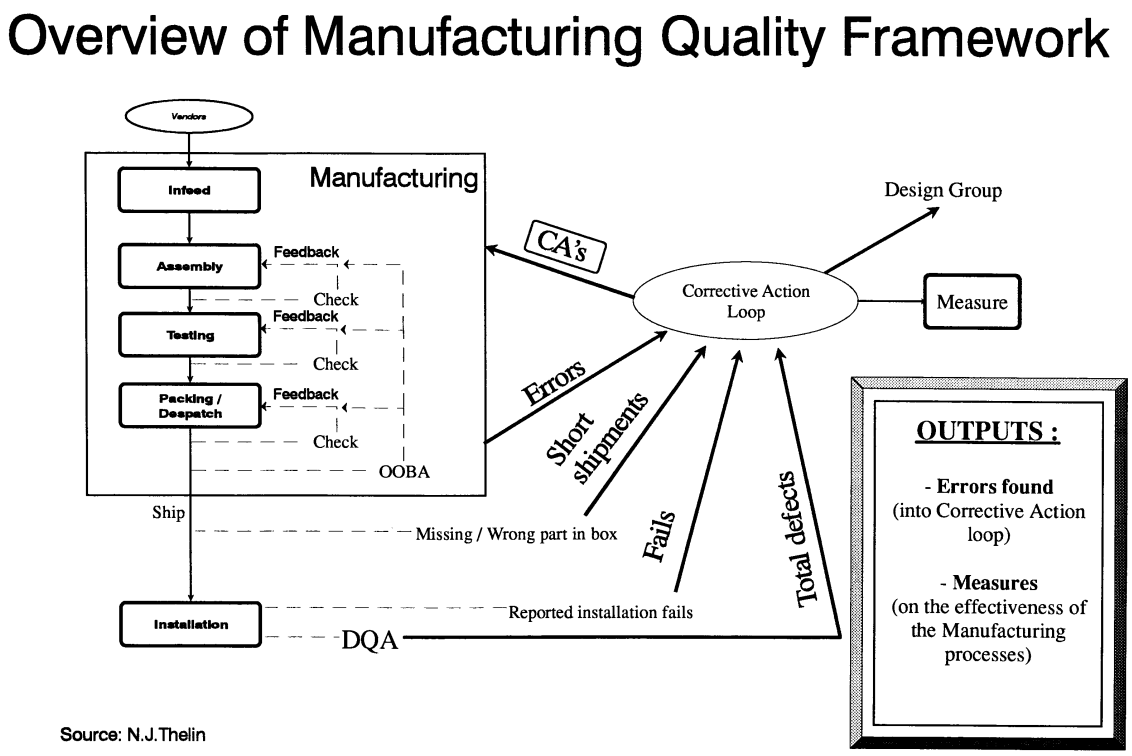

Figure 5 - Ashton Manufacturing Quality Framework overview

4.2.1. Measure of Delivered Quality

Measure product Delivered Quality by focusing on the manufacturing attributable installation defects, rather than Early-Life (design related) problems.

Problems feed into the generic Corrective Action loop outlined below (section 4.2.2).

4.2.2. Corrective Action Process

Ensure a coherent Corrective Action Process exists to reliably address all problems found during Installation & Commissioning (I&C), Out-of-Box Audits (OOBA) and Delivered Quality Audits (DQA) to root cause and correction at source.

4.2.3. Prevent problems on New Product Introduction: MPV

Establish the Manufacturing Process Validation framework to trap problems on new products as part of the introduction process into the factory, before the build up ('ramp up') to full production volumes occurs.

This represents the initial proving of the processes, both to 'debug' them, and to ascertain that they are capable of producing the new product.

4.2.4. End-of-Line / Out-of-Box Audits

As an immediate measure, first screen out problems just before shipment, to trap problems in-house. This is to implement Sirkin & Stalk's first problem solving loop ('Fix-as-Fail' ie. reworking or fixing the product before it is sent to the customer) [Sirkin & Stalk, 1990].

Then, implement & improve audit procedures to push error detection and correction closer to source, ie. earlier in the manufacturing process, as processing of already defective parts or products only increases the overload on any bottle-necks in the production cycle [Goldratt & Cox, 1989]. This action is to implement Sirkin & Stalk's second problem solving loop ('Prevention' ie. without tracing problems to their root causes, enabling rapid feedback of problems from the point where they can be discovered to the people who can prevent them from happening).

The problems identified through these audits are fed into the CA loop mentioned previously, to provide full root cause corrective action. This is to implement Sirkin & Stalk's third problem solving loop ('Root Causes' ie. find the actual root causes of the problems, and correct them).

Use the Out-of-Box audits to provide a measure of the overall effectiveness of the manufacturing processes. Note, the efficiency of the processes are measured through Process Yields (Fresh Lot Yields), and are entirely separate from the effectiveness of the processes at delivering conforming product with all 'infant mortalities' removed.

Such process yield issues are outside the scope of this project, and so will not be covered further.

4.2.5. Delivered Quality Audits

Delivered Quality Audit's provide a fuller assessment of the conformance quality of products than can typically be measured through the Installation Defects measurement above in 4.2.1.

They do this by an auditor actually being present on a customer's site when the product is delivered and installed, and thus being able to observe and report any deviations or non-conformances present in the shipped product.

Thus, DQA's provide a unique feedback mechanism for continuous monitoring and improvement of total delivered quality.

The findings from these audits feed into the same corrective action process previously mentioned in 4.2.2.

5.MANUFACTURING QUALITY FRAMEWORK - DETAILS

Having seen an overview of the quality framework, this chapter looks at each element involved in greater detail.

5.1. Measure of manufacturing delivered quality

As already mentioned in chapter 4, the first stage of the implementation of the new quality framework was to change the measure of product Delivered Quality to focus on the manufacturing attributable installation defects, rather than Early-Life (design related) problems.

This was the first key step towards Manufacturing Division's vision of "Zero Defects Plug & Play", outlined previously in chapter 3.

5.1.1. Comparison with old measure

The old measure of 'Plug & Play' is the system ICL Manufacturing used to measure defective output, and is calculated by comparing the output during the month against the number of failures ("ICOR" warranty claims) recorded during that time period, and using these figures to calculate the percentage of systems output that did install and work successfully. Thus, if output was 100 units, and 5 systems failed, the "Plug & Play" metric for that period would be 95%. Plug & Play is calculated for whole systems, not for each individual part or feature output.

There are some inherent problems with the Plug & Play metric, principally that the matching of the output figure with the failure figure is very loose, due to the usual practice of units not being installed immediately after output, either through the inherent delays in the distribution and sales channel, or customers storing the products until they are ready to install them.

Also, the ICOR Warranty that Manufacturing provide on its products lasts typically for 28 days from the start of installation, which not only covers the defects or failures found during installation, but also the Early life failures that are due to the inherent reliability characteristics of the design. As discussed previously (section 4.1), the overall reliability of the design is not considered to be Manufacturing's responsibility.

The new measure of 'Defects per Installation' was designed to specifically avoid these problems. This measure also provides a much clearer focus on the two key facets of manufacturing quality, namely conformance to specification, and removal of infant mortalities in the factory.

This new measure operates by specifically counting the number of Installation Service Request Calls on the UK Customer Service call handling system (CRISP). The number of failures, or other defects (eg. short shipments or on-site engineering repair work), are also taken from the CRISP system where they are either recorded as completion comments on the Installation call, or as specific failure calls raised to obtain spares or extra system expertise.

5.1.2. Key features and benefits

The key features and benefits of the new measure are:

a. **Exact matching of defects against number of systems installed.**

Systems do not get counted until they are actually installed. Also, fails are related directly to the installation they originate from by tracking the progress and status of the Installation calls.

This avoids the very rough 'guess work' previously involved in trying to match the output from the factory with the installation fails reported. That was one of the worst problems with the old Plug & Play measure, and in many ways made the data at best very difficult to work with, and at worst misleadingly useless.

Also, overseas problems where previously not necessarily visible for inclusion in the data if they were resolved locally, which again would distort the picture as they would be counted in the output figure.

b. **Includes all types of defects**

The old measure focused on functional failure of parts, but this new measure encompasses all types of installation defects, including short shipments and any other problems reported through the Customer Service call logging system. Any on-site action taken to correct faults is recorded on the progress and closure messages of the Installation service call.

This is precisely the point that Garvin makes when discussing the conformance dimension of product quality [Garvin, 1984], ie. that measuring conformance by counting service calls or warranty repair claims neglect other deviations from standard (such as misplaced labels or shoddy construction) that do not necessarily lead to service or repair.

While it is accepted that all conformance deviations will not be reported through Customer Service calls, any that are known about need to be included, and Delivered Quality Audits are used to provide a fuller assessment.

c. **More realistic representation of "bad" installations.**

Under the Plug & Play measure, a "disastrous" installation would get masked by the statistics, as if that site had (say) five problems/defects, it would just count as one system failed to 'Plug & Play', the same as another system that had just one defect.

Under the new measure, such multiple defects are specifically counted and represented in the 'defects per installation' figures, and would count 5 against the 1 for an installation with only one problem.

Thus, the new metric gives a much clearer picture of the extent of the problems manufacturing is causing for it's customers.

5.2. Corrective Action process

To support the investigation of installation defects, as well as back up the other quality processes that will be described later, a coherent Corrective Action (CA) Process needs to exist to reliably address all quality problems found, such as Installation & Commissioning (I&C), End-of-Line / Out-of-Box Audits (EOLA/OOBA) and Delivered Quality Audit's (DQA). The Corrective Action process needs to consistently identify root cause and successfully implement correction at source.

Key features of the process are:

- Operator "ownership" of problems
- Correction at source
- Fix problems generically (fix the process)

5.2.1. Operator "Ownership" of problems

It is extremely important that production operator's "own" the quality problems, for several reasons:

a. **Responsibility at source**
As Schonberger and others point out, one of the key requirements for 'Total Quality' is worker responsibility for the parts or products that they make [Schonberger, 1982].

b. **Visibility of problems**
This also forces one of Schonberger's other key Total Quality Control/Management concepts, namely 'Easy-to-see' quality, ie. that problems are visible and known about by Production, and not merely confined to the Quality Department(s).

c. **Involvement**

It also causes operator involvement in the resolving of problems, which Hall identifies as one of the three pillars of Manufacturing Excellence [Hall, 1987], along with Quality Improvement (which is the ultimate purpose and aim of the CA process), and JIT (which is already a given at Ashton).

5.2.2. Correction at source

Correction at source is vital to move from what Sirkin & Stalk describe as the first to the second and third problem solving loops, which are vital for real and lasting quality improvement [Sirkin & Stalk, 1990].

Sirkin & Stalk's problem solving loops are:

1st **Fix-as-Fail**
ie. reworking or fixing the product before it is sent to the customer.

2nd **Prevention**
ie. without tracing problems to their root causes, enabling rapid feedback of problems from the point where they can be discovered to the people who can prevent them from happening (ie. learn to detect the problem situations, and thereby not pass them on).

3rd **Root Causes**
ie. find the actual root causes of the problems, and correct them.

4th **Anticipation**
ie. predicting market needs for product or quality improvements before they are actually required.
This allows time to develop the product and systems necessary to intercept the 'window of opportunity' in the market when it occurs, thus becoming a pro-active leader in the market, rather than merely a late follower.

Key elements are therefore:

a. **Feedback problems to the line production units.**

Feeding back problems to production ensures that problems are visible to the people that need to take some action to improve the situation, ie. those that have the necessary authority to effect changes (what Harrison describes as "the most important principle of quality organisation" [Harrison, 1990]).

b. **Investigation of real root cause**

Where the problem originated is the only place that the real cause of the problem can be investigated, using all the evidence available. This also involves the 'experts' on the operation under investigation (ie. the workers who perform that operation frequently) in deciding what action should be taken to rectify the situation.

This not only involves the workforce in Total Quality, but it also taps the extensive 'knowledge base' that exists among these workers.

5.2.3. Fix problems generically (fix the process)

This is particularly important in a high product mix manufacturing environment, as the specific problem may well exist on more than just this product. In a Total Quality and continuous improvement system, it is important that these same problems are prevented from occuring on similar products, without having to wait until the problem is encountered on that product also, with all the inherent 'fixing' and rework costs that would entail. This is what Sirkin & Stalk describe as "learning from the problems", and not continuously fixing the same problems over and over again [Sirkin & Stalk, 1990].

In practice, this resolution of the "generic" problem, rather than just this specific instance, is one of the hardest things to achieve in a "product team" structured unit, as there is usually little communication or "cross fertilisation" of experiences between the different product units.

Therefore, the two main ways that this "cross fertilisation" of experiences and problem solutions can be achieved is through:

a. **Senior Management Quality Review**

The higher management involvement in this meeting means that the level of responsibility of the people involved spans production of more than just a single product, so this meeting automatically results in the wide awareness of at least the major problem experiences in each area.

However, while this awareness process operates and is effective for major problems, the lesser problems will almost certainly not be visible, primarily because of the senior level of participants in this meeting.

b. **Feed into organisational memory base**

In practice, this is probably the only way for an organisation to "learn" from the less serious problems, and implement a true Total Quality / Continuous Improvement system.

This allows the minor problems to be recorded and shared at an operational level, without the inherent un-desirability of this level of detail being presented to the senior management reviews.

One of the easiest methods of implementing this type of organisational memory base is through use of 'checklists' that provide a list of common, specific and/or recent problems that need to be remembered or borne in mind for this or all products and operations.

As Shingo points out, use of such a checklist is a very effective 'Poka-Yoke' ("mistake-proofing") system from preventing defects [Shingo, 1986].

In practice, to prevent the checklists being unmanageably complex, the number of items to consider needs to be kept to a reasonable size, primarily through the removal of problems where full root cause corrective actions have been implemented, which by definition cannot recur (as they have been eliminated forever [Crosby, 1979]).

5.2.4. The GENERIC CORRECTIVE ACTION PROCESS

Thus, a generic process needs to exist to receive all types of reported defects or quality issues, and is represented diagrammatically below:

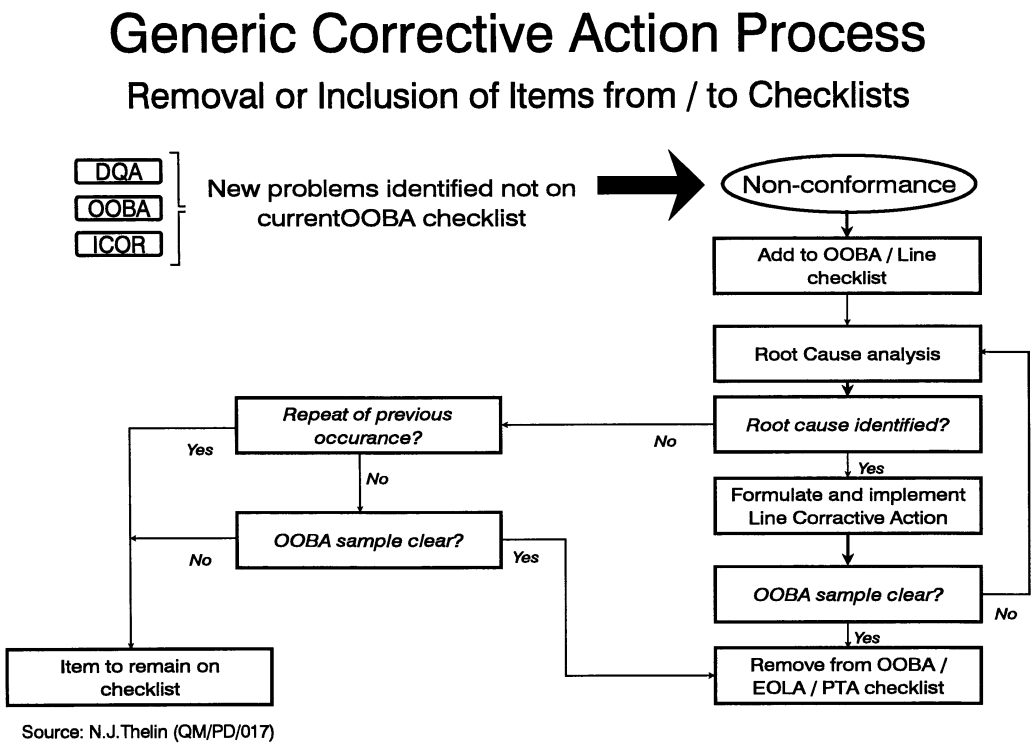

Figure 6 - The Generic Corrective Action Process

5.3. Prevent problems on new products

As already outlined, the existing product introduction processes in use at Ashton did not appear to be pulling all of the initial problems out of the product, and hence the early 'Plug & Play' on these products drops once volume shipments start.

Therefore, it was decided to establish the 'Manufacturing Process Validation' (MPV) framework to trap problems on new products as part of the introduction process into the factory, and provide a fuller validation of manufacturing's readiness for full production volumes, before the eventual ramp-up occurs.

The key idea that underpins the MPV is the concept of 'process proving', ie. checking out the process before it is used "in anger" at the eventual target production rate.

Once this capability has been established, the processes can be left to operate largely unobserved.

There is an obvious similarity here with the normal 'Ship-to-Stock' system employed in Just-in-Time manufacturing, namely that once the new part / supplier has demonstrated that it is capable of delivering the quality and consistency required, no further 'goods-inward' type checks are applied (or only infrequent "confidence" sampling).

The author's personal concept of Total Quality Management is embodied in the summary equation:

Conforming inputs + Capable processes = Consistently conforming output

The MPV is therefore aiming to confirm up front that the inputs (materials, tools, jigs, etc) conform to requirements, and that the manufacturing processes have the capability to produce the end product, which results in confidence that the output of this product from the factory will consistently conform to specification.

Historically, Manufacturing validation for a new product or feature has consisted of a Product Validation Trial (PVT) which focused specifically on proving the build and test activities through process auditing.

To provide a fuller evaluation of the capability of the Manufacturing processes to deliver a consistently conforming product, the original PVT is being expanded into a Manufacturing Process Validation (MPV) for proving the complete end-to-end manufacturing cycle, and to more fully cover the totality of new product activities.

5.3.1. MANUFACTURING PROCESS VALIDATION (MPV)

The MPV framework defines the generic requirements for the validation and proving of the end-to-end manufacturing processes for new product or feature introductions into Ashton Manufacturing.

This provides a framework to relate the operational activities involved in proving and obtaining confidence in the end-to-end manufacturing process.

It is split into three stages:

Process Proving (PP)
- Manufacturing in-feed & assembly activities.

Product Trial (PT)
- Diagnosis & testing activities.
- Product quality.

Route Proving (RP)
- Output, shipping and installation activities.

Below is a diagrammatic overview of the stages and activities involved:

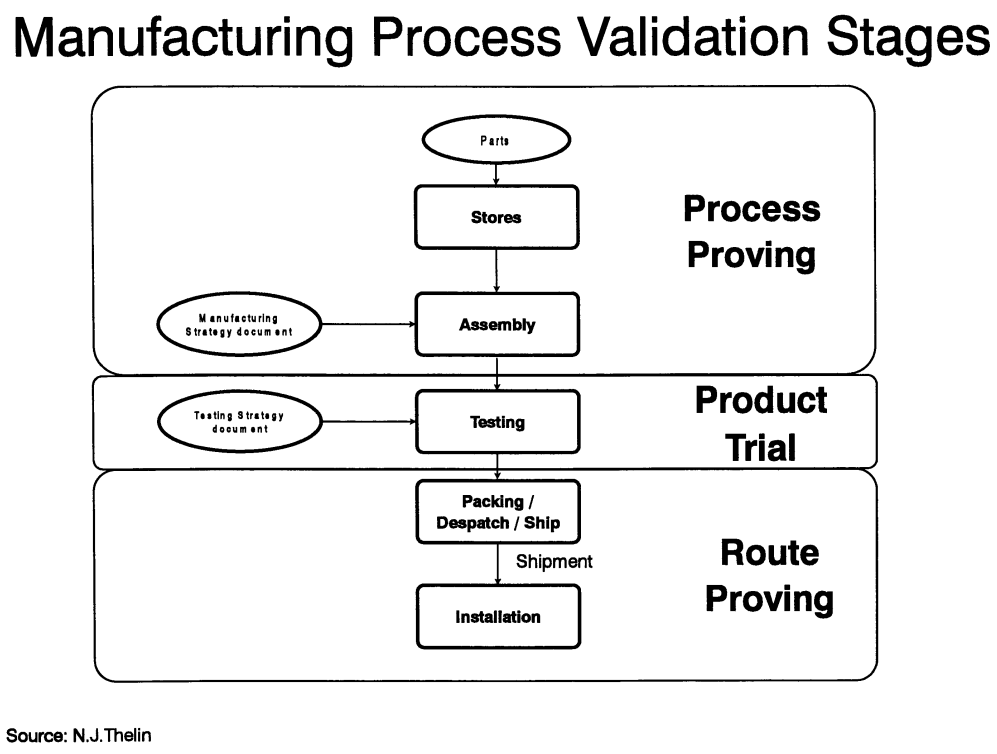

Figure 7 - Manufacturing Process Validation (MPV) Stages

During the MPV activities, a log is maintained of all problems and defects encountered, together with the resolution action and closure details. This provides a major input into the decision process on whether to release the product for volume shipments, through sign-off of the Product Release Certificate (PRC).

It is important that during the MPV, the individual manufacturing processes are run as near as possible to the target activity rate and cycle time of the eventual full scale production, to ascertain whether the processes will be able to withstand this level of loading.

It is not specifically required that the individual validation activities within the MPV are performed serially in strict sequence, and in fact some overlap and parallelism is desirable to minimise the overall Time to Market for the new product. The sequencing that will be used in this instance needs to be defined in the MPV activities plan.

A more detailed examination of the activities and areas covered in each stage is provided in the following sections.

5.3.2. "Process Proving" (PP)

This stage is to obtain confidence that all manufacturing in-feed and assembly activities are functioning, and are capable of delivering a conforming product.

It specifically does not cover any of the activities to prove the capability of the product before output, e.g. by testing.

The main methods to be used to evaluate these activities will be:

First-off inspections
Process Audits
End-of-Line Audits (EOLA)

plus

Ensuring the materials supply and other support systems are functioning during the process audit.

A summary of the areas covered by this stage of the MPV is outlined in the following diagram:

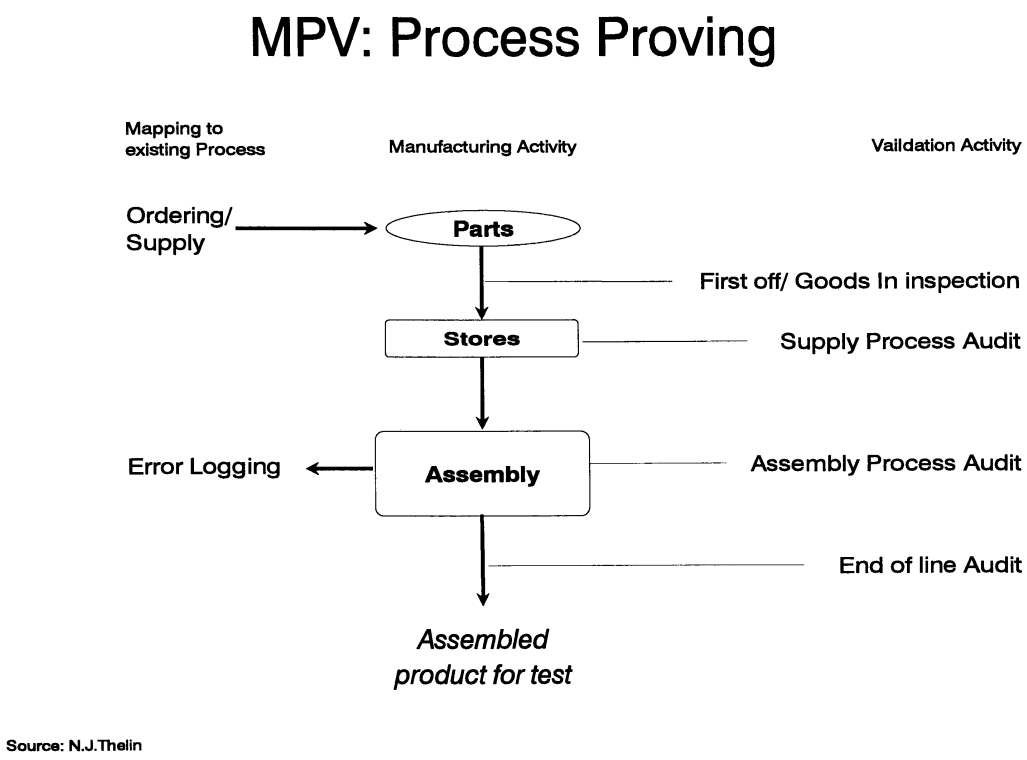

Figure 8 - MPV - Process Proving

1. **First-off Inspections**

   Inspection of all new parts introduced by the new product introduction, against controlled drawings.

   Appraisal of any new vendors introduced for this product.

2. **Assembly Process audit**

Audit the assembly operations performed for the first production batch that ...

- Uses the final :
  * parts,
  * suppliers,
  * modification (mod) levels of parts,
  * work instructions
  * assembly aids, and
  * build and test locations,
- Follows the definitive Manufacturing Strategy.

3. **Supply Process audit**

Audit the in-feed activities performed for the first production batch, to confirm that the supply processes are in place, and functioning to deliver the right parts, from appropriate suppliers, in the right timescales, at suitable cost.

In practice, this involves a fairly detailed checklist of items relevant to the Purchasing & Materials Supply organisation and systems. A detailed discussion is beyond the scope of this document.

This should also consider the Process Yield achieved by any in-house PCB manufacturing operations, which are typically viewed as simply a "vendor" to the assembly plant.

4. **End-of-Line audits**

100% sampling of initial production batch, at the end of the assembly and test operations, to provide a peer check that everything is correct (what Shingo describes as a 'Successive Check' [Shingo, 1986]).

After normal production starts, it is expected that on-going auditing will continue after the MPV on a sampling basis, typically 1% of output, or as agreed with the Quality Reliability Manager.

5. **Error Logging**

   Confirm that the error logging processes are in place and functional, especially LQS (the Ashton fault recording and logging system). This will confirm that the necessary part numbers are known to the system, and that suitable product and production stage codes have been defined for this product to allow the capture of accurate fault data.

5.3.3. "Product Trial" (PT)

This is to obtain confidence that the activities for proving the performance of a unit before shipping are satisfactory, in terms of covering product quality (fitness for purpose), and diagnosis and testing activities.

The main methods to be used to evaluate these activities will be:

Process Audits
Product performance evaluation
Out-of-Box Audits (OOBA)

plus

Ensuring the support systems are functioning during the process audit.

A summary of the areas covered by this stage of the MPV is outlined in the following diagram:

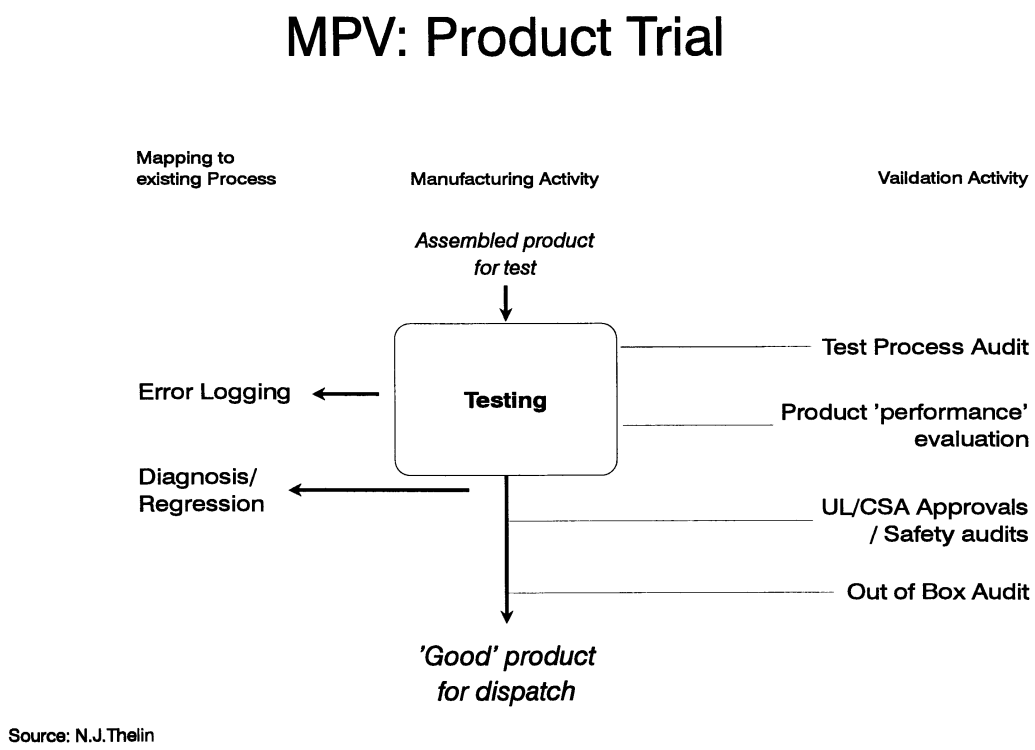

Figure 9 - MPV - Product Trial

1. **Testing process audit**

Confirm that the definitive high level Test Strategy is in place, and authorised by the relevant authorities.

A Testing Process Profile must have previously been defined, and approved by Quality Reliability Manager. This outlines how the detailed testing will be performed, such as what temperature the systems will be thermally stressed at, and for how long.

Test procedures must be in place, to provide detailed operational work instructions to test engineers.

Confirm that the testing process is functioning, and delivering sufficient test coverage, in particular that fails are being found early enough in the overall test process. The overall assessment of this is likely to be based on the profile of failure rates for each testing stage.

Prove that the process satisfactorily detects defective parts, sub-assemblies and printed circuit boards, by applying known faults.

2. **Product performance**

Confirm that product performance (i.e. fitness for purpose) and reliability are satisfactory.

This is really an assessment against all the other seven dimensions of quality apart from conformance [Garvin, 1984], but primarily it concerns (early-life) reliability, giving a guage of how much testing will be required to pull out infant mortality fails in the factory.

As well as feedback from the normal product testing processes, this will be assessed by a formal Reliability Trial (or other Reliability Assessment based on accumulated product exposure during the overall validation process) against the Design & Marketing Reliability Targets.
It will follow a Trial Plan produced by the Product Introduction function within the Development Group involved, and agreed with the Customer Service organisation (UKCS) and Manufacturing. This is to ensure that the key customers of the development group (UKCS and Manufacturing) are happy that the product has been exercised suitably before release.

Sign off of the Trial Report upon completion will be by the same three parties as for the plan. This provides visibility of the results, and agreement on satisfactory completion of the trial.

After normal production starts, it is expected that ongoing reliability trials will be performed after MPV on a rolling sample, as agreed with the Quality Reliability Manager.

3. **Out-of-Box Audits**

100% sampling of initial production batch after all the testing activities are completed and the product is being dispatched, again providing a Shingo 'Successive Check' [Shingo, 1986].

After normal production starts, it is expected that on-going auditing will continue after MPV on a sampling basis, typically 1% of output, or as agreed with the Quality Reliability Manager.

4. **UL/CSA Approvals**

Confirm the UL/CSA Approvals file is set up as necessary. (This covers the formal product liability insurance requirements in certain countries, notably the USA.) Audit a sample of the initial production batch against this Approvals file, to confirm satisfactory conformance.

This will also confirm that the safety testing operations (such as Earth continuity and Flash testing) are satisfactory, and meet the legal requirements.

5. **Fails Regression route**

This is the defined process or handling route specifying what to do with parts or printed circuit boards that fail at some point during the production & testing activities.
In most cases, the failed part is likely to be confirmed as faulty (typically by a Technical Support group) before being returned to the vendor under a supply warranty, or repaired in-house, depending upon the part and the type of fault.

A key question with such situations is how much of the testing of the system that has already occurred must be repeated, ie. what is the "return point" for each test stage in the process?

Therefore, the MPV needs to confirm that 'Regression Rules' are adequately defined for the retesting of failing systems.

As part of the MPV, it is also necessary to confirm that the regression route guarantees full testing before output of any part or component, ie. that failed parts do not "slip through" the testing net.

6. **In-House Diagnosis procedures**

Confirm that the In-house Diagnosis Process is in place and functional, ie. set up to handle any new or changed PCB's or parts.

Diagnosis and Repair Route responsiveness targets should have been defined, and measurement be in place and operational.

Confirm that defective components are successfully handled by the diag route, ie. that the Technical Support group can successfully diagnose known faults.

Confirm the repairability (to 'as-new' state) of product and parts, through the successful repair of faulty parts at an appropriate repair centre.

7. **Error Logging**

Confirm that error logging processes are in place and functional; at Ashton, this is primarily the LQS database, but also other diagnosis and known error systems such as Ashton's MFCC and ASK systems.

5.3.4. "Route Proving" (RP)

This is to obtain confidence that the output, shipping and installation activities are in place, and capable of delivering a system to the customer that will work first time ("Plug-in and Go").

A summary of the areas covered by this stage of the MPV is outlined in the following diagram:

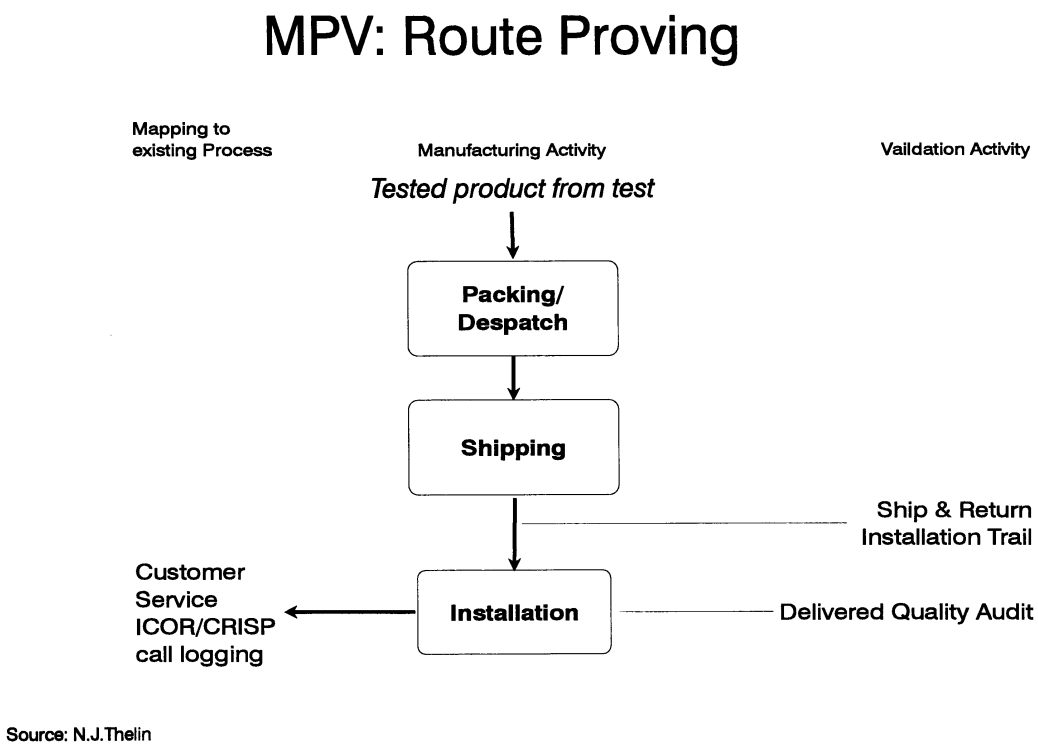

Figure 10 - MPV - Route Proving

1. **Ship and Return Installation Trial**

   Using all the final packing, documentation and loose features, fully pack the units ready for shipment.

   Then, unpack and install units on-site using the normal field installation process, i.e. UKCS Engineer Procedures and Guides as necessary.

   At least one of the units must be shipped to the Product Distribution Centre, unloaded into normal storage, and then traded back and return to Ashton (or another nominated location) to be installed as above.

   This will not only confirm the protection provided to the product in transit by the packaging is adequate, but also that the Product Supply and Physical Distribution systems and processes are ready for the product.

   A full Out-of-Box & Delivered Quality Audit check should be made on these activities.
   Any problems noted should be included in the event log, but may also be issued as a formal Product Introduction DQA as well.

   A typical minimum number of installation trials for each 'range' of products are defined in the MPV procedure, with the actual planned numbers in this instance needing to be specified in the MPV plan for this product.

2. **Delivered Quality Audit**

   Perform a full Delivered Quality Audit (DQA) on the first customer shipment, plus a minimum of 5 of the first 25 orders.

   The installation of these units should follow the normal UKCS / Customer installation procedure.

   This allows any early problems with the product in the field to be rapidly trapped and resolved.

   After normal production starts, on-going Delivered Quality Auditing will be performed as defined in the DQA Schedule for each product group.

3. **ICOR Warranty Process**

   Confirm that the ICOR (Installation & commissioning warranty) processes are in place and functional, especially UKCS CRISP call routing through LOCATE (1st Line Support) to the appropriate ICOR authorisation and processing desk. At least one service call should be raised through the central UKCS Call Reception Centre to prove this.

5.3.5. Generic framework

The MPV was designed as an overall framework that could be applied to any type of product or feature part introduced into Ashton Manufacturing, including any transfer of any production activities from other Manufacturing Units.

It also applies equally to "specials" involving new customised variants or hangering requirements (pre-installation and configuration of software, and testing of complete system setup before shipment), or other "value-added services" offered by Ashton Manufacturing.

While the MPV framework is a generic outline, it can (and should) be "particularised" for each product it is to be applied to by deciding whether any of the activities have already been satisfactorily completed (perhaps no new component parts are involved, so no "First-off's" would be required, and also deciding exactly how each of the activities will be performed, including any "parallelism" that can be introduced into the plan.

Due to the generic nature of the framework, the MPV approach could be applied in any high-mix production situation, and could even be applied to a service environment with minimal alteration.

5.3.6. Comparison of MPV with Development 'V'-model

Using a typical V-model of a standard development process (this is the version used by ICL [ICL Technology & Engineering Group, 1990], but is equivalent to similar models used by other companies), it is possible to view the end-to-end manufacturing process as a "development" process, and map the MPV steps onto these standard stages.

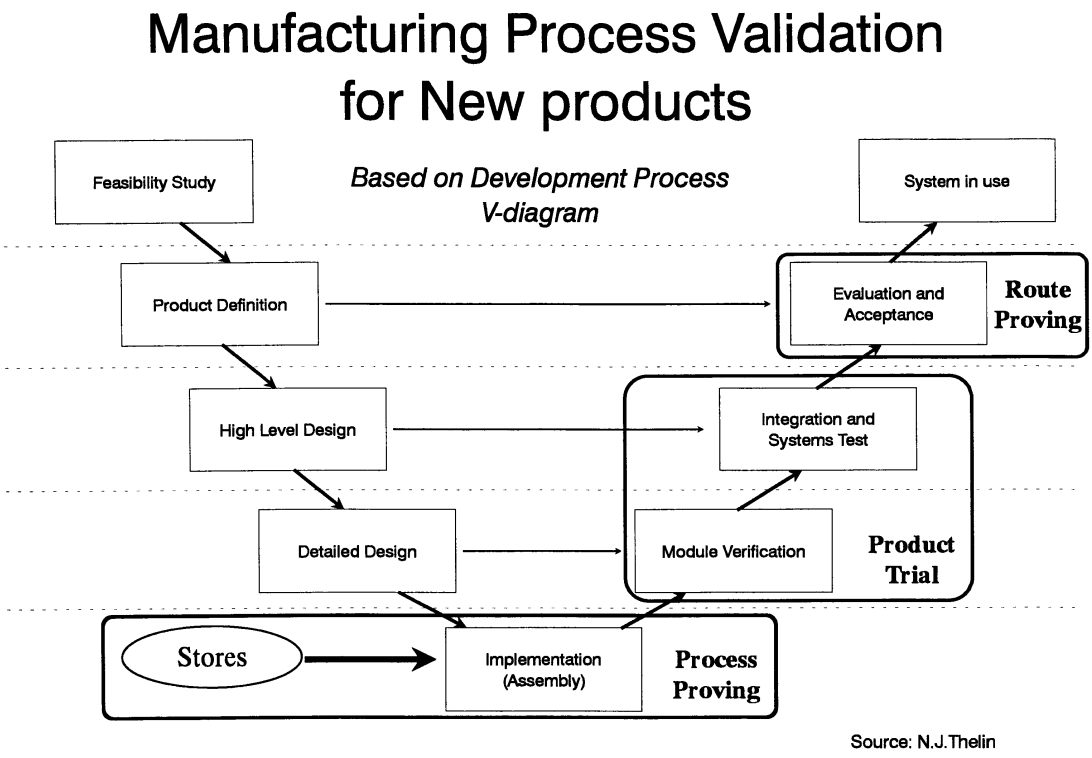

Figure 11 - Relationship of MPV stages to Development V-diagram

One interesting point to observe when this is done is that the amount of proving checks and trial activities performed equate very closely with the typical stages undertaken in a usual design or development process.

Another interesting point is that the validation activities performed in the MPV extend beyond the product completion and shipment from the factory, into the phases of acceptance and use of the system. These phases are not often covered extensively, if at all, in typical development processes.

5.3.7. Record of historic/common problems

One of the main outputs from the MPV activities is a list of the events or problems encountered with the introduction of this product, which will either be resolved before general release of the product, or used in the product release assessment (PRC) to determine the action plan for clearance.

This list of events is really one of the key purposes of the MPV checks, to build up a checklist of historic or common problems on previous products (of this type, or other related products).

In this way, an organisational memory base can be built up and maintained to improve the validation activities on future product introductions.

This also serves to record the experience of the current participants in the product introduction process, and preserve this knowledge for use in the activities to introduce future products, for example to highlight items that require special attention, because they are frequently a source of problem. In this way, the 'expert' experience that accrues through a series of product introductions can be preserved, and 'passed on'.

5.3.8. Learning across product ranges

The recording of product introduction events, and production of MPV checklists, also allows the opportunity of sharing the accrued experience and learning across different product ranges and types, which was described earlier (section 5.2.3) as one of the most difficult tasks of information sharing and organisational learning.

5.4. Trap problems before shipment

A vital element of the MPV process for new products is the "End-of-Line" audit (EOLA). By using an independent peer check of a product at the end of assembly and test before shipment, it allows detection and resolution of problems with a product before first shipments to the customer commence. It also feeds into the organisational memory base of typical problems on new products introduced.

In a similar way during normal production operations, End-of-Line audit methods can be used to allow the same detection and resolution measures to continue after General Release of the product.

The way that these audits are performed can have a very different effect on the overall effectiveness of these activities. Such audits can either be performed at the very end of the whole assembly and test process, or else at the end of each stage within these processes. This leads to two very different situations from a quality system point of view.

In the former situation, we have effectively reintroduced 100% inspection, although with some learning possibility dependant upon the feedback and resolution methods used. As Shingo points out, just adding more inspection in itself is not going to reduce defects, as it does not prevent defects from occurring in the first place, just filters them out after they have occurred [Shingo, 1986].

In the latter situation, we have what Shingo describes as 'Self-Inspect' [Shingo, 1986] if the operator performs the checks before passing the product on to the next stage, or 'Successive Checks' if the checks are performed by the next "downstream" production stage, both of which give swifter and more certain feedback of problems directly to the source.

Therefore, all of the above methods are critically dependant for their overall effectiveness in reducing defects not on the audit or inspection methods themselves, but on the existence and effectiveness of the feedback and Corrective Action process that supports it; the requirements on which have already been described previously (section 5.2).

To be completely effective, the auditing / checking process must be integrated into the operational stages as peer-based successive checks.

While the End-of-Line audit is intended to act as a "screen" to trap problems in the factory before shipment, there is a similar audit (the Out-of-Box Audit, OOBA) that is intended solely to provide a confidence measure of the continued conformance and capability of the overall manufacturing processes.

Thus, we are taking a statistical sample from each product group output in a set time period to act as a process measure of the effectiveness of the manufacturing operations for that product.

This is a very similar concept to formal Statistical Process Control methods, ie. checking that the process is still in control and within defined capability limits. The OOBA concept could, in theory, be treated as an acceptance sample for the batch of that product output during that time period, although this is specifically not the intention of that audit.

The diagram below shows how the different types of audit mentioned relate together, and how they fit into the general manufacturing processes. Following that is a more detailed description of the Out-of-Box Audits, which are the key measure of the on-going manufacturing process capability.

5.4.1. The Generic Out-of-Box Audit Process model

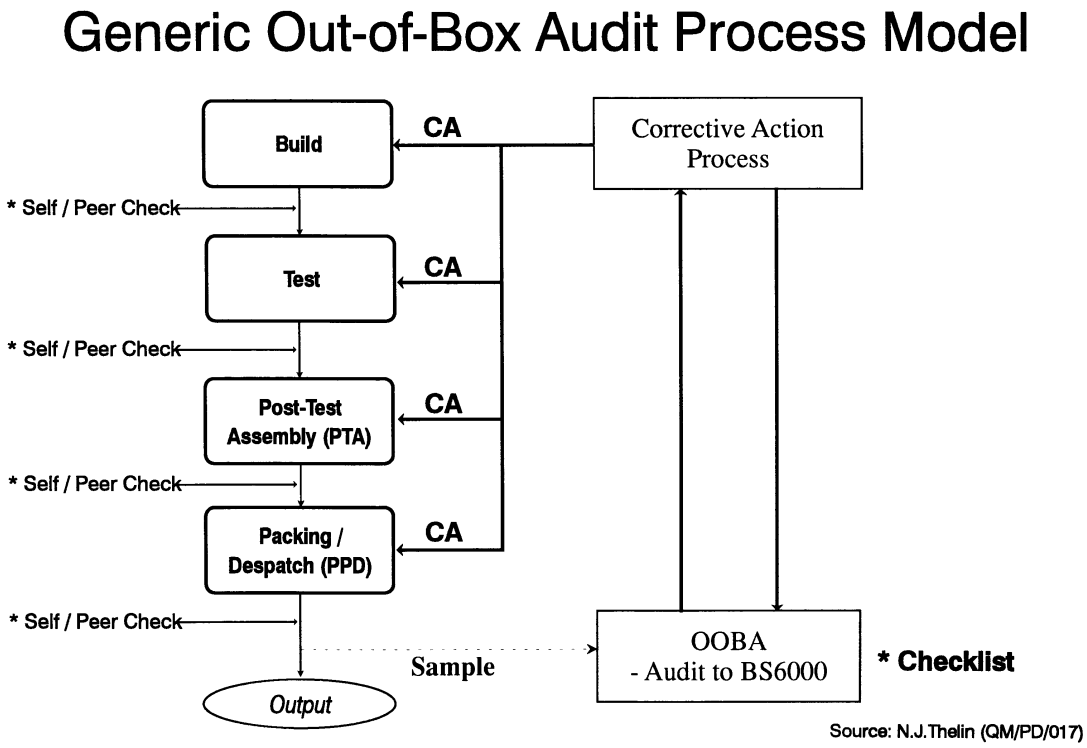

Figure 12 - The Generic Out-of-Box Audit Process

5.4.2. Out-of-Box Audits

a. Purpose of Out-of-Box Audits

The focus of the Out-of-Box Audit (OOBA) is very different from the conformance checks in End-of-Line audits. In OOBA's, we are taking the position of customers who have just received this product, unpack it and simply attempt to "Plug-in and Go".

The purpose of an OOBA is to act as a measure of the conformance quality [Garvin, 1984] of the factory output, and so provide confidence that the internal manufacturing processes are operating effectively to deliver product that conforms to the customer's quality expectations.

OOBA's should take place at the point just before the item is dispatched to the customer, after all assembly and test activities have been completed (see diagram above - section 5.4.1).

In particular, the full feature kit of items to be shipped with that order must be present with the unit / system to be output when the audit takes place.

OOBA's are specifically not intended to find problems at this late stage in the process, nor to act as a screen to filter out problems that would otherwise have reached the customer.

b. Areas to be Checked

The following generic areas should be checked :

1: Cosmetic finish and appearance

2: Normal Installation & Commisioning operations
- opening / removing any customer or engineer access covers
- power up (if feasible)

3: Functional operation (if feasible)

4: Check that all items (units, features and accessories) to be output for this order are all present, and nothing else.

c. Audit Operations

The procedures or work instructions for OOBA's on each individual product define the exact sequence of operations to be performed in that audit.

One of the key items to be defined is the extent and nature of any power-up or functional tests that will be performed for each product in the OOBA.

All auditing activities must provide minimum disruption to the system and configuration that will be shipped to the customer. In particular, any testing that requires (temporary) alterations of configuration or settings should not be performed, to prevent the possibility of introducing new errors or defects at this stage.

It is vital that OOBA's are performed by a person who was not involved in the rest of the assembly and test process for that particular unit / item.

The specific list of items to be checked for each product will be defined in the OOBA checklist for that product, which needs to be specific to that product not just generic.
This checklist must detail all the aspects that should be specifically checked or confirmed, and especially recent or recurring problems.

All failures, defects or faults that are recorded must be categorised in terms of the severity and impact they would have on the customer.

All parts that fail during an OOBA must be treated as *I&C* (Installation & Commissioning) fails for investigation, diagnosis and corrective action processes. This applies in particular to responsiveness timescales and priority.

5.4.3. Checklist - organisational memory base

Once again, the checklists used in the End-of-Line audits and Out-of-Box audits represent further opportunities for increasing the organisational knowledge retention and memory base and improving the cross-product learning, as previously outlined in section 5.3.7.

As such, they have an important place as part of the generic Corrective Action process loop. (See section 5.2.3.)

5.5. Customer view of problems : Delivered Quality Audits

As mentioned previously (section 5.1.2), the use of service calls and warranty fails in the installation measure does not always provide a complete picture of the conformance level of products from the factory, as other deviations from standard do not necessarily lead to service or repair.

Delivered Quality Audits (DQA's) complement the Installation measure by providing an impartial assessment of all the conformance aspects of deliverables as supplied to the end customer.

DQA's also provide a unique and revealing picture of a customer's total satisfaction with the product delivered.

Such an audit may either cover the complete process from order placement through to hand over to the customer, or may focus on particular areas within this process. All audits are performed by trained ICL auditors.

A major feature of these audits is that, wherever possible, the auditor speaks directly to the customer to obtain their perception of the products and services received.
In particular, DQA's provide a guage of Garvin's final two dimensions of quality, namely aesthetics and perceived quality [Garvin, 1984], through soliciting and recording direct feedback from the customer. In this way, DQA's provide a very valuable method of assessing two of the most difficult dimensions of quality to measure.

All issues, including those raised directly by the customer, are categorised by severity and assigned a "criticality score". From these, an overall criticality score (or customer dissatisfaction score) for each audit is derived.

A monthly Delivered Quality Audit Review meeting is held, hosted by Manufacturing and with representatives from Design, Sales and Customer Service, to monitor the status of all non-conformances and issues raised as a result of the audit programme. Corrective action plans are presented and reviewed to ensure successful implementation of corrective action, based around the generic Corrective Action process at Ashton, as previously described in section 5.2.

So far as is known, the Delivered Quality Audit process is unique to ICL. It is considered to be a "leading edge" process, which could be adopted by other companies with ease, and which has shown to yield great benefits in identifying additional non-conformance items, gauging a measure of the two most subjective dimensions of quality, and assessing overall customer satisfaction with the product delivery.

The above describes in detail the overall quality frameworks and processes at Ashton Manufacturing, and how they interrelate. The next chapter will examine what actually happened during the implementation of this framework, and what the current status is.

6.ACTUAL OUTCOME

As is usually the case, the actual outcome of the project did not go completely to plan, and all the activities are not completely finished and implemented at the time of writing.

In this section the current state of the project is examined, before looking in the next chapter at the lessons that can be learned from these experiences, and finally to look at recommendations for the future.

6.1. Delivered Quality Measurement

All product areas are using the 'Defects per Installation' measure, although their is still a desire to produce the "old" Plug & Play measure for comparison purposes.

As can be seen from the P&P Trend Graph (Fig 2, Section 2.1), the delivered quality of products shipped has generally improved during the timescales of this project, although the DRS6000 and DX mainframe have recently been experiencing new design faults that have affected the metrics.

6.2. Manufacturing Process Validation

The Manufacturing Process Validation was the first part of the framework to be put in place (starting in July 1992). This worked reasonably well, with the effects of some of the extra parts of the validation activities being evident almost immediately - in particular the installation trial involving the Customer Service Engineers.

However, due to the turbulence caused by redundancies during this time, and other turn-over of staff in the area that performs the new product introduction and validation activities, the original briefing and education on the principles and requirements of the MPV system have had to be re-taught and re-learned by the people now involved in the activities, which has obviously resulted in a considerably slower pace of implementation, and a reduced effectiveness of these operations in the meantime.

6.3. Corrective Action loop

A corrective action loop very close to the required form described previously already existed in the Large Systems production unit. It was being used for one of the types of problem described ("ICOR" installation warranty claims), but has now successfully been expanded to cover the other types of problems (Delivered Quality Audits and End-of-Line / Out-of-Box audit actions).

An example of the generic nature of the CA process is the fact that it is now also successfully being used to handle all types of similar issues requiring action, including those from Internal and External Quality Systems (ISO9000) and Process audits.

On the other hand, the DRS6000 production unit has made little progress in establishing an effective feedback and corrective action loop, although efforts are continuing in this area.

The High Volume production unit lies somewhere in the middle. It has a CA loop which does work, but is not quite as developed or fully utilised as the Large System unit.

The key difference between the relative success of the three areas is directly related to the amount to which the root cause analysis and determination of corrective action is performed by the production operators and supervisors, or by the Production Manager for the area. The latter is the least effective, as in general there are an overwhelming number of other pressures swamping these Production Managers, and secondly because the production operators are the "experts" on the production operations. These operators are in the best position to identify and resolve problems in their operations, and their involvement is vital to the effective implementation of any changes required.

There is a clear lesson here on the necessity of operator involvement in the corrective action process.

6.4. Mistake Proofing - Audits & Checklists.

The Large Systems production unit has successfully been using "ticksheets" during the testing process for some time.

These detailed the main problem areas to check for, and resulted in a very successful 'Successive Check' [Shingo 1986] system where key elements of the assembly process were checked by the next "downstream" stage. This resulted in problems being discovered in a very short time within the process.

However, these checklists did not document all the recent assembly problems that could or should be found, and was only used by that one part of the process.

Since then, similar checklists have been produced for the other areas of the Large Systems production process, and have proved effective.

A very sophisticated and detailed series of checklists have been developed in the DRS6000 production unit, including photographs of certain key elements to check, and structured in such a way that all the key problems were checked by at least two different stages (self-inspect and successive). Unfortunately, this has not yet been fully implemented, due to several reasons, including change of key staff and output pressure. Prior to this, the principle has been for Self-inspection (operators examine their own work for defects, using a much smaller checklist), but in practice this has not been very effective.

Out-of-Box audits have been implemented on all products.

6.5. Delivered Quality Audits

The Delivered Quality Audit system has been in use by Ashton for a considerable time, and continues to be very effective at revealing non-conformances in product output from the factory. It is applied to all product ranges shipped.

6.6. Organisational Knowledge Retention

The main cause of the underlying problem encountered with the implementation of this project centred around what I will call "the fundamental economics of manufacturing".

In the current economic climate, with continuing recessionary pressures on businesses, manufacturing plants face continuing challenges to reduce the overhead and cost base of the businesses.

The fundamental economics of manufacturing are that, in any situation, it is better to have a job done by a suitable younger person of lower salary grade (and hence cheaper) than an older / higher grade person.

While greater age or experience are not the criteria for selecting candidates for redundancy when necessary, continuing economic uncertainty will continue to have the effect of the removal from the fixed overheads of many of the oldest staff, either because they have accumulated a sizeable redundancy package, or because they have been unable to keep up with the increasing demands placed on manufacturing staff.

The older workers will be on higher pay differentials due to length of service and having received more pay increments, and thus they will give a large reduction in overhead costs.

However, this leads directly to the key problem encountered, namely that the staff with the most accumulated experience depart, leaving junior staff who have considerably less experience. The remaining staff thus does not have so much history or memory of the type of problems likely, and hence do not have the knowledge of the main problems to look out for in any specific situation.

While they can develop this experience base eventually, this is certainly a slow process, and almost certainly too slow in a high throughput / high mix environment with rapid introduction of new products and ever decreasing 'time to market' (product introduction cycle time) requirements, as experience will be based on cumulative exposure to each different problem on every individual product type / model.

Hence, one of the key lessons from these experiences is the need for some way of recording and preserving the collective past experience of previous product introduction, and previous engineers.

Key to this is the realisation by the junior staff of the reasons why this is necessary, and recognition of the value of updating and preserving such a 'knowledge base' for current and future use.

In the manufacturing situation, the main form that such a 'knowledge base' will take is likely to be a 'checklist' of specific items and areas to be checked at each stage, eg. during the Out-of-Box Audit, or during the Manufacturing Process Validation activities, specific to the type of activities to perform, and listing the key items to observe or confirm.

6.7. Staff changes - experience

Through these staff changes the amount of experience has decreased substantially, particularly in the Production Engineering area. This means that although the right type of tools & systems are in place, the newcomers to the job often do not understand why the best practices that are embodied in the quality frameworks are important, and as a result are prone to taking tactical decisions that compromise these processes.

Hence, there is a clear need for coaching and re-education of the key staff on the reasons for the prescribed best practices.

6.8. Organisational Structure

As mentioned in the Introduction (section 1), due to the events of the last 6 months, and especially the sudden departure of the General Manager, the design of the organisation has "evolved" in response to these occurrences.

However, that has resulted in a few anomalies in the structure of the organisation, and particularly in the relationship and responsibilities within what was the Production Operations Centre. This unit is made up of the Line Production unit and the Production Engineering unit, which previously reported to the Operations Manager. In this setup, the Production unit was largely responsible for output of products at the required time (the Delivery and Cost parts of Macbeth's Manufacturing Deliverables [Macbeth, 1989]) and Production Engineering were largely responsible for technical support and diagnosis of problems, including resolution of issues notified by field units (Macbeth's Quality deliverable [Macbeth, 1989]).

Here there is an important distinction between three key elements of management:-

* **Responsibility**
  - required to take some action, or make some contribution to an activity or change.

* **Authority**
  - approval of the activity or changes / right to veto.

* **Accountability**
  - required to explain the eventual success or failure of the activity or changes.

In the above situation, the authority to implement changes to work operations lies with the Production Manager, but the responsibility and accountability for those changes lies with the Production Engineering Manager. In a similar way, the accountability for the quality of the product output lies with the Production Manager, but the responsibility and authority for finding the root causes of quality issues and deciding what needed to be done to resolve the problem lies with the Production Engineering Manager.

A key symptom of this non-alignment of the responsibility, authority and accountability for product delivered quality is the fact that the Production Manager(s) do not present the Installation metrics for their products at the Quality Review meetings, and hence never experience the full reaction to adverse figures and trends.

Ordinarily, the coordination of the above Operations activities to ensure achievement of Macbeth's three manufacturing deliverables was performed by the Operations Manager. However, when the Operations Manager moved up to the Factory General Manager's position in November 1992, with a considerable widening of scope of activities and responsibilities, the Production Operations units continued to report to that person. In this situation, the Factory General Manager would be required to continue to provide the coordination role, although this has previously been proved to be a full time job in its own right.

Therefore, some other method needs to be found to provide that coordination within the Production Operations function, and allowing the General Manager to focus on the business aspects of running the factory, which are becoming more important with the moves towards autonomous profit-centred business units.

7. LESSONS

7.1. Successive checks, not self-inspection

The value of successive checks has been proved in the Large System production unit, and the disadvantage of the self-inspection approach has been visible in the DRS6000 production unit.

Therefore, there is a clear benefit in favouring peer-checking and other forms of checking at "downstream" stages.

To control the checking, and limit the number of possible items that need to be checked for at each stage, some form of checklist or tick-sheet needs to exist, and be regularly updated [Shingo, 1986].

7.2. Need for Organisational memory / learning

As mentioned several times, many of the problems encountered can be directly traced back to the lack of accumulated experience and retained knowledge within the organisation.

In this situation, the organisation's knowledge base is being diminished through the loss of experienced staff.

Hence, it is becoming increasingly important for the organisation to be aware of the need to learn from past problems and experiences, and to develop ways to perform and retain this learning within the organisation.

Even Manufacturing now needs to be regarded as a "knowledge-based" business!

7.3. Tactical response to diminishing experience

When in a similar situation to that described in this dissertation, where the retained knowledge and experience in an organisation is diminishing, some tactical measure is required to act as a "stop-gap" measure until the experience can be built up again.

In this case, the necessary response needs to be to prescribe standards of good practice where the knowledge of, and reasoning behind, previous "custom and practice" has been lost or dissipated.

This needs to be followed up with a coaching or "education" process, to teach the understanding of the good practices to the less experienced staff who have not experienced the previous situation.

7.4. Implementation of change

In almost all cases, the pace of progress when implementing changes will be slower than that initially envisaged.

The implementation of changes can be critically affected by external events that have not been foreseen, and as a result, the implementation plans on occasions can be almost "event-driven", with the change efforts being distracted by these events.

In particular, this predicates the need for a "programme manager", who is singly accountable (section 6.8) for the overall success of the implementation, even if this involves working with others that may have the responsibility and authority for actually performing the operations and activities. This programme manager is what Wilson & Rosenfeld describe as a "change agent" [Wilson & Rosenfeld, 1990], which is perhaps a more apt description of the task.

It is also usually vital that the changes have a senior "champion", who has sufficient authority to overcome any stubborn obstacles encountered. Wilson & Rosenfeld refer to this as the necessity of an internal change agent to have a "substantial power base", and having "political support".

7.5. Making the change stick

This is typically one of the most difficult tasks involved in a change, and is what Lewin refers to as 'refreezing' the balance of driving and restraining forces to maintain equilibrium in the new desired state [Lewin, 1951].

An example of the difficulty of this task is the simple case of the use of the term "MPV - Manufacturing Process Validation". This was deliberately chosen to be a completely new phrase that would distinguish the new practices from the previous practices of a "PVT - Product Validation Trial", and emphasise the concept of exercising and validation of the total manufacturing process.
However, the term has not "stuck" uniformly throughout the organisation - some people still refer to "PVT"s, and others to the hybrid "MVT - Manufacturing Validation Trial".

It is also interesting to note comments by Juran, who makes the point that all management activity is directed at either "breakthrough" or "control" [Juran, 1964].
Breakthrough is the creation of good changes, where a whole system is changed, while Control is the prevention of unfavourable change and making sure that standards are adhered to.

This provides a useful insight and lesson about this situation. While the vast majority of the changes and improvements to the quality frameworks described in this dissertation represent "breakthrough" activity, it is also vital to back this up with "control" to make the changes stick.

7.6. Organisational structure

As Macbeth points out, to be successful, a company must achieve the manufacturing deliverables of 'quality' and 'delivery' simultaneously [Macbeth, 1989] (and 'cost', although as Macbeth asserts control of costs follows automatically from achieving the other two). In particular, Macbeth makes the point that trading one of these deliverables off against the other will not be successful in the long run, as does Harrison through his coining of the phrase "the three-legged stool of production" [Harrison, 1990].

Therefore, each key manufacturing line units (Production and Purchasing & Materials Supply in the case of Ashton) need to have objectives covering all three of the above manufacturing deliverables to prevent what Hall describes as "sub-optimised myopia" [Hall, 1989].

This Line unit responsibility is working very effectively with PMS, who now have responsibility for the Vendor Quality function, to provide a balanced set of objectives covering all three of the above manufacturing deliverables (which are also directly applicable and necessary to the Supply function - what Harrison has termed the "three-legged stool of buying" [Harrison, 1990]).

The reason this situation works from an Organisational Design stand-point is that the responsibility, accountability and authority (see section 6.8) for the achievement of 'Manufacturing Deliverables' for material in-feed are aligned with the organisational unit boundaries [Harrison, 1990].

7.7. Operation variety

Even within a single "unit" like the Ashton factory, it is important to recognise the inherent differences between the diverse sub-units, such as the production of the individual product groups, and find ways to allow these beneficial differences to be accommodated.

Hence, it is vital to practice what Peters & Waterman describe as 'Loose / Tight Fit' [Peters & Waterman, 1982], ie. recognising that some things are best done differently by individual groups, while others are best "standardised" across the multiple units.

In the case of quality systems, in practice this boils down to defining generic policies & frameworks (= tight) that document best practice, but allowing "particularisation" (= loose) of these by the owner of each area to suit the individual circumstances of that area, thus fulfilling the optimal balance for that unit.

This accommodation of beneficial variety is really the true meaning of the phrase 'Plant within a Plant'.

7.8. Statistical Process Control

Without some specific measure of the overall outcome of the manufacturing processes, we have no real idea as to whether these processes are functioning incorrectly until we receive warranty or repair requests from the field on products we have shipped some time previously.

This means we have no way of accurately relating the problems experienced with any known state of the process performance, due simply to the fact that so much time has elapsed from introduction to discovery of the problem.

Statistical Process Control is the usual method prescribed for measuring the operating characteristics of a process.

Drucker describes Statistical Quality Control (also known more commonly in the West as Statistical Process Control - SPC) as :

> *"A rigorous, scientific method of identifying the quality and productivity that can be expected from a given production process in its current form so that control of both attributes can be built into the process itself."*
>
> *"SQC [SPC] can instantly spot malfunctions and show where they occur. Because it can do this with a small sample, malfunctions are reported almost immediately."*
>
> [Drucker, 1990]

Schonberger points out that "formal" SPC are not the only way to achieve this end, and that hybrid or "quick and dirty" techniques can be used to yield the same results of "gaining control over the process" [Schonberger, 1986].

However, all parties are agreed that some overall design, study and measurement of the process as an entity is necessary to control the capability and consistency of the output, and provide early warning of process problems.

7.9. Key to Improvement - Involvement

The key element of all the Quality Improvement activities is the Corrective Action loop / process.

This must feed problems back to the source of the problem, and must involve the production operators in the resolution of the problem, as they are the "experts" on the activities that have caused the problems.

7.10. Review of Quality Systems

A continuous or periodic review and renewal of quality processes & systems is necessary to keep the quality operations of a company in tune with its changing internal and external environment.

Even "best practices" may need to change over time, as requirements change, although it is expected that the general quality frameworks described in this dissertation will be a suitable method of unifying these changing practices for some considerable time in the future.

It is also important to be aware of the inherent operational or performance limits of existing quality practices, and hence be aware when a "quantum leap" change is required, rather than just simple evolutionary changes.

8.FUTURE RECOMMENDATIONS / FURTHER STEPS

8.1. Need for organisational learning / memory base

Checklists are a vital tool to preserve a record of the key issues and items to check.

They need to be applied to all applicable areas, principally in-process checks and new product introduction validation.

Also, these checklists need to be kept up to date, and developed further.

8.2. Organisational structure

The responsibilities of Production need to explicitly cover the overall delivered product quality requirements, to align the accountability, responsibility and authority for product quality with current organisational boundaries.

8.3. Process overview

There is a need to maintain a high-level view on the manufacturing processes, recognising the generic similarities, but also acknowledging the specific differences.

It is important to pursue synergies and learning across the processes for the different product groups.

8.4. Process measurement

More use needs to be made of suitable methods to monitor the overall effectiveness of the manufacturing processes and provide early warning of developing problem situations.

This is particularly applicable in the two dimensions of product quality that are relevant to manufacturing - ie. removal of infant mortalities before shipment, and conformance (Zero Defects).

Without this, it is not realistically possible to expect to achieve 'Zero Defects Plug and Play' (which is the overall quality vision of ICL Ashton Manufacturing).

8.5. Continue Implementation of the Quality Framework

It is necessary to continue the implementation of the quality framework outlined in this dissertation.

Particular items that will be pursued are :

- Use of the in-process checklist for DRS6000 production
- A generic feedback & CA loop for DRS6000 production
- Specification, and enforcement, of standards of operating good practice during the MPV activities, to provide the tactical response to the reduced experience levels.

8.6. Quality Education programme

The Quality Department are already planning a series of events within the factory (which have been termed "Quality Kick-offs"), to teach and re-emphasise the quality processes and best practices.

8.7. Operator Involvement

The only way that Quality Improvement will be truly effective is through the full involvement of all staff in the quality and improvement activities within the factory.

The dELTA system is being implemented during 1993 to encourage and channel this involvement.

8.8. Read Shingo!

The book "Zero Quality Control: Source Inspection and the Poka-yoke System" by Shigeo Shingo [Shingo, 1986] should be required reading by all manufacturing personnel, but especially those with Production responsibility. The messages that book contains are phenomenally powerful and enlightening!

8.9. Test the Generic application of the framework

Using any appropriate opportunity, an attempt should be made to apply the quality frameworks described in this dissertation into another location and situation (either within ICL or outside) to confirm the stated belief of the general applicability of these practices to any "world class" manufacturing environment.

9.REFERENCES

[Crosby 1979]
Crosby P.B., Quality is Free : The art of making quality certain, Mentor, 1979.

[Drucker 1990]
Drucker P.E., The emerging theory of manufacturing, Harvard Business Review, May/Jun 1990, pp94-102.

[Drury & Thelin 1992]
Drury M.R. & Thelin N.J., Achieving Zero Defects Plug & Play, Unpublished Internal ICL discussion document, 10 June 1992.

[Foo & Friedman 1992]
Foo G. & Friedman D.J., Variability and capability : The foundation of competitive operations performance, AT&T Technical Journal, Jul/Aug 1992, pp2-9.

[Garvin 1984]
Garvin D.A., What does "Product Quality" really mean?, Sloan Management Review, Fall 1984, pp25-43.

[Goldratt & Cox 1989]
Goldratt E.M. & Cox J., The Goal, Creative Output Books, 1989.

[Hall 1987]
Hall R.W., Attaining Manufacturing Excellence, Dow Jones-Irwin, 1987.

[Harrison 1990]
Harrison D., Quality Organisation and Programmes, pp13-31 in Lock D.(Ed), Gower Handbook of Quality Management, Gower, 1990.

[ICL Technology & Engineering Group 1990]
ICL Technology and Engineering Group, Development Process Handbook, Internal ICL handbook, 1990.

[Juran 1964]
Juran J.M., Managerial Breakthrough, McGraw-Hill, 1964.

[Lewin 1951]
Lewin K., Field Theory in Social Science, Harper & Row, 1951.

[Macbeth 1989]
Macbeth D.K., Advanced Manufacturing : Strategy and Management, IFS, 1989.

[O'Conner 1985]
O'Conner P.D.T., Practical Reliability Engineering (Second edition), John Wiley & Sons Ltd, 1985.

[Oakland 1989]
Oakland J., Total Quality Management, Butterworth-Heinemann, 1989.

[Parker & Harrison 1992]
Parker T.P. & Harrison G.L., Quality Improvement using Environmental Stress Testing, AT&T Technical Journal, Jul/Aug 1992, pp10-23.

[Peters & Waterman 1982]
Peters T.J. & Waterman R.H., In Search of Excellence : Lessons from America's best-run companies, Harper & Row, 1982.

[Schonberger 1982]
Schonberger R.J., Japanese Manufacturing Techniques : Nine hidden lessons in simplicity, Free Press, 1982.

[Schonberger 1986]
Schonberger R.J., World Class Manufacturing : The lessons of simplicity applied, Free Press, 1986.

[Shingo 1986]
Shingo S., Zero Quality Control : Source Inspection and the Poka-yoke System, Productivity Press, 1986.

[Sirkin & Stalk 1990]
Sirkin H. & Stalk G., Fix the Process, Not the Problem, Harvard Business Review, Jul/Aug 1990, pp26-33.

[Wilson & Rosenfeld 1990]
Wilson D.C. & Rosenfeld R.H., Managing Organisations : Texts, readings and cases, McGraw-Hill, 1990.