CRANFIELD UNIVERSITY

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ORGANISATION OF IN-PROCESS INSPECTION AND CONTROL OF THE LAMINATION PROCESS IN CARBON FIBRE COMPOSITES MANUFACTURING

SCHOOL OF INDUSTRIAL AND MANUFACTURING SCIENCE

Masters of Research (MRes) THESIS

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Organisation of in-process inspection and control of the lamination process in carbon fibre composites manufacturing

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ABSTRACT

The lamination process is the core in the manufacture of carbon fibre composites. This thesis is a detailed study of the manner in which in-process inspection can be organised so that process flaws that subsequently result in defects can be eliminated or minimised. The quality management system and the inspection methods in force at Lola are thus subjected to intensive scrutiny so as to identify opportunities for improvement.

A review of relevant literature on quality management, continuous improvement, mistake-proofing and zero defect initiatives helped map out a methodology for the research. The literature has also looked at the human issues that influence quality and inspection methods.

The approach to the study has been to establish quality performance in the past and at present, establish quality attitudes and evaluate inspection methods. Visual inspection is the widely used method of inspection within the industry and instrument aided methods are still an area for research. Ways in which defects may be prevented from occurring and analysing the defects when they occur so as to get to the root causes have been suggested.

This study has highlighted the need to adhere to standard operating procedures which account for errors that are avoidable. Motivation and inspiration can only be cultivated into workers through recognition and rewards. Employee engagement is very crucial and workers need to be supported with focussed training and appropriate working aids.

Recommendations have been made on involving workers right from the design stage through the manufacturing process right to the customer. Customer

requirements will need to be executed with certainty and all necessary information deemed useful will must be input at the design stage. In-process inspection must take a holistic approach i.e. both horizontal and vertical inspection. A point worth noting is that visual inspection accounts for at least 80% of inspections carried out in the manufacture of carbon fibre composites.

ACKNOWLEDGEMENTS

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GLOSSARY OF TERMS

LRIT	Liquid Resin Infusion Technology
PDCA	Plan; Do; Check and Act
IQE	Individual Quality Experience
F.M.E.A	Failure.Mode.Effect.Analysis:
DFMEA	Design Failure Mode Effect Analysis
PFMEA	Process Failure Mode Effect Analysis
QFD	Quality Function Deployment
SPQL	Shipped-Product Quality Level
AQL	Acceptable Quality Level
SQCS	Statistical Quality Control System
MTBI	Mean Time Before Improvement
SuCS	Successive Check System
NDI	Non-Destructive Inspection
CAA	Civil Aviation Authority
QMS	Quality Management System
NDI	Non-Destructive Inspection
TQM	Total Quality Management
NRFT	Not Right First Time
DITFR	Do It Right First Time
PDNC	Post-Delivery Non-Conformances
RCFA	Root Cause Failure Analysis
PCAR	Preventive and Corrective Action Request
ISO	International Standards Organisation
BS	British Standards
NVQ	National Vocational Qualification

1. Introduction

1.1 Industrial background

Lola Composites is part of the Lola Group which also incorporates Lola Cars. It is located in Huntingdon, Cambridgeshire, United Kingdom. It is a global player in the supply of advanced carbon fibre components to the aerospace, defence, automotive, communication and space, marine, medical and science sectors. The last 20 years has seen the birth of Lola and the subsequent growth in reputation as a supplier of reliable, high quality and high performance products.

Lola applies state-of-the-art lean and agile techniques to tool and manufacture its products to meet both time and cost targets. It is also its specialty to produce high quality carbon fibre tooling for a wide range of its products. Lola products are mainly made from pre-impregnated materials and Liquid Resin Infusion Technology (LRIT). LRIT provide benefits in that it allows Lola to produce a wide range of products at low cost. Manufacturing is carried out under the auspices of BS EN ISO 9001:2000 Quality Management System. Lola's work meets the quality approval systems for major companies like Airbus, European Space Agency, EADS Astrium, Sikorsky Helicopter under FAA, BAe Systems, Lockheed Martin, Meggitt Defence, Marshall Aerospace, UK Ministry of Defence etc. Lola's tooling manufacturing is also approved by GKN Aerospace and Bombardier Aerospace. At the present moment, Lola is working towards attaining AS 9100 Aerospace Quality approval system.

1.2 The Industrial Problem: An Overview

The focus of this project is to carry out an in-depth study of the lamination process in order to establish the process flaws and shortcomings which consequently adversely affect the quality of work from this process. The origins of mistakes which are then transformed into defects need to be identified. Despite Lola Composites' investment into training and development of its human resources quality problems still remains a major concern.

The process is fully manual and hence is prone to mistakes, thus it has also become critical to understand the human factors that come into play. It must be realised that this is more of an art than a science thus errors due to inadvertence, lack of technique and wilfulness are all possible. The current practices of in-process inspection and control will be challenged in a bid to unearth work methods that are responsible for products that do not conform to requirements.

The focus of the project will also go beyond the workers, who by virtue of them being responsible for executing the actual work play a major role in deciding the fate of the product in as far as quality is concerned. The other issue that will be investigated is the quality system in force at Lola and management involvement in quality. The researcher will need to evaluate management commitment as it is the most important driver of quality improvement.

Manufacture of composites has traditionally been viewed as “black art” or sculptor processes that depended more on company or operator specific knowledge. The demand for improved product quality and consistency has significantly changed this approach. Carbon fibre composites’ superior mechanical properties, which match those of conventional material like steel and aluminum, coupled with their weight advantage have given them widespread use in such industries as the aerospace, motor-sport, sporting goods etc.

1.3 Aim and Objectives

From the issues raised above, the overall aim of the project is ‘to develop the organisation of in-process inspection and control of the lamination process in carbon fibre composites manufacturing.’

To attain this aim the following objectives have been established:

a. To investigate and evaluate the current lamination process, its organisation and control methods and identify the likely sources of mistakes.
b. To develop an in-process inspection strategy based on employee involvement.
c. To study the human factors that affects the quality in the lamination process in composite manufacture.
d. To evaluate and recommend methods of inspection: - low-tech, high-tech or both methods.
e. To suggest continuous improvement strategies for the business.

Deliverables that the researcher intends to bring forth out of the study are:-

a. Highlight the strengths and flaws of the current quality management approach.
b. Recommend a quality improvement strategy appropriate to Lola.
c. Recommend economic inspection methods and techniques aimed at error elimination and guaranteeing quality as a permanent feature of business practice.

2. Literature Review

2.1 Introduction

The measurement, control and reduction of product variability are some of the fundamental objectives of the quality organisation within manufacturing companies. Quality assurance is critical if composite technology and manufacture is to reach its full potential. Although this project is going to focus on the quality control for the laminate manufacturing stage, it must be noted that material quality approval and inspection of fabricated components are equally important if we are to adopt a holistic approach. The literature search or review will be divided into three sections which will seek to focus on:-

a. An overview of quality management; which will
    - bring forth a working definition of quality that should relate to Lola.
    - understanding the cost of quality and non-quality in the business context.
    - highlight impediments to implementation of continuous quality improvement initiatives.
b. The impact of human factors on quality.
c. Tools and techniques that may be used to resolve problems when they occur.
d. Inspection methods and techniques.

2.2 An Overview of Quality Management

2.2.1 Defining Quality

The concept of quality with respect to the customer has always been in the business world but the study of quality is relatively new, dating back to the early part of the 20^{th} Century asserts Kolarik [17]. The word '*quality'* means a lot of things to a lot of people. It is common to hear such phrases as '*good quality', 'bad quality,' 'quality of life'* and in these cases 'it is only used to signify the relative worth of things'. [8]. Wollschlaeger, [31] looks at quality as two dimensional and says of it, '*It is the uniformity, the consistency, of the products, and the product's conformance to specification.'* His second view is that '*Quality is the perceived grade of the product in the market place.'* Dale [11] also acknowledges that *'quality as a concept is quite difficult for many people to grip and understand and much confusion and myth surround it… there is no single definition of quality.'*

Juran [16] however limit the definition of quality to '*fitness for purpose.'* In [11], BS EN IS0 9001 (2000) define quality as '*the degree to which a set of inherent characteristics fulfils requirement.'*

For the purpose of this project, quality will be defined as 'conformance of the product to requirements.' [8], [11]. Conformance to requirements is explained to mean '*the degree of conformance of all the product's features and characteristics to the product requirements specification and the stated requirements of users.'* [21]. Crosby [8] further argues that quality is tangible and can be measured by the cost of quality by *'cold hard cash.'*

At this point it will also be useful to define improvement as this term will find widespread use in this project. '*Improvement means the organised creation of beneficial change, the attainment of unprecedented levels of performance.'* [16].

2.2.2 Process Quality vs. Product Quality

Process quality is more than product quality, and these cannot be equated. Process quality is the means while product quality is the result. [7]. Beside the product which he looks at in terms of effectiveness, Conti [7] also add two other products of process quality as efficiency, thus keeping cost and execution time to a minimum and elasticity i.e. being able to respond to rapid changes.

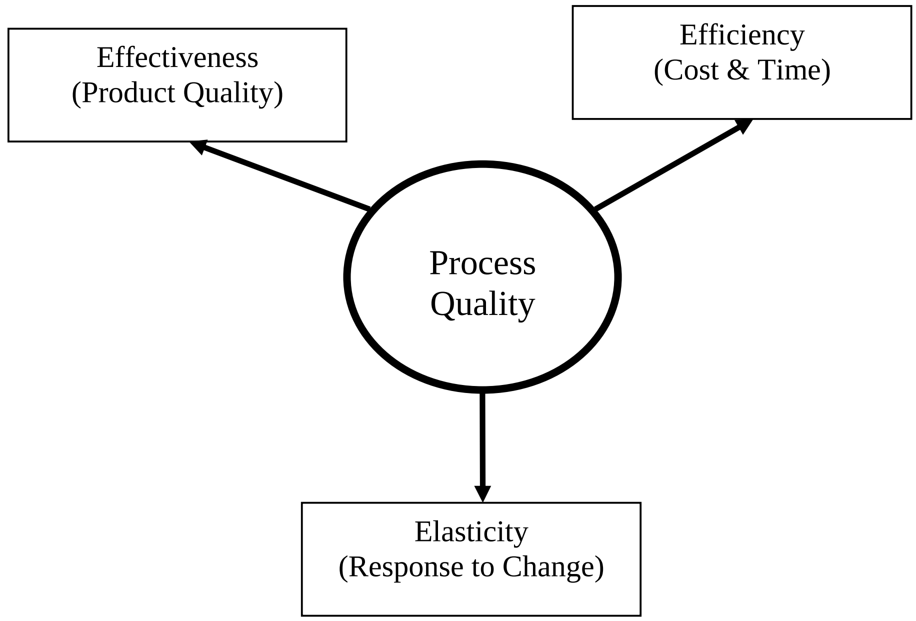

Figure 1: Process Quality (Source: [7])

2.2.3 Quality Costs and Economics

Quality is measured by the price of non-conformance. Cost of quality has two components i.e. the price of non-conformance and price of conformance. [8]. The sum total of all things done the wrong way constitutes the price of non-conformance. Crosby [9] estimates these costs to be 20% or more of sales in manufacturing and 35% of operating costs in services. Use the price of non-conformance to track improvement initiatives and areas that prevent the highest returns for improvement opportunities. [9]. Quality has a strong and positive impact on corporate economics and hence should improve the company's business results. [7]. The basic problem of the economics of quality lies in maximising value and minimising costs.

The price of conformance is concerned with what is just required to get things right. Issues that need to be put right include prevention effort, quality education, procedures and product qualifications. [9]. Quality costs can be grouped as follows:

a. Prevention costs: - associated with designing, implementing and maintaining the quality system.
b. Appraisal costs: - associated with measuring, evaluating or auditing products and materials to assure conformance to requirements.
c. Internal failure costs:- associated with defective products or material failures that result in manufacturing loss.
d. External failures costs: - these arise when defective components are shipped to customers. [31].

Mohla [20] quote these costs to be broken down as follows:

Prevention	5%
Appraised	30%
External & Internal	45%
Exceeding requirements	10%
Lost Opportunity	10%

Table 1: Quality Costs Breakdown (Source: [20])

Costs that are linked to doing things right first time are preventive costs. Effort need to be channelled to prevention so that costs associated with doing the wrong things amounting to 95% can be reduced.

2.2.4 Barriers to Improvement

Barriers that can threaten the quality improvement process according to Nacelles and Dale [21] are;

- nature of management leadership an organisation has
- fear of change
- lack of necessary skills to articulate improvement
- lack of information to support the improvement process.

2.2.5 Nature of Management Leadership:

According to Nacelles and Dale [21], '*British managers revel in crisis management and perceive this to be their most important task.'* Reactive management and fire-fighting, rather than planning and taking action to anticipate the future is a show of managers who fail to defined their objectives and often see the discovery of problems as an opportunity to shine as dynamic and macho trouble-shooters. [21]. It is important to note that this view has not been substantiated by other sources and opinion may vary. There is a strong tendency for transactional leadership or 'once only' input to quality improvement often typified by the Quality Managers being delegated the responsibility to implement and manage quality improvement while the top leadership adopt '*the do it but……keep me informed*' attitude. [21].

There is generally an absence of organisation for pushing quality improvement, as part of the company's business plan. Quality improvement requires mandated responsibility evaluated against mandated standards and not for managers carry out quality improvement on a voluntary basis." [16]

If the goal is to accelerate the pace of strategic renewal or to fully engage the imagination and passion of every employee, then management need to show the employees that they can influence the direction of the business strategy as both implementers and creators of the strategy. [13]

2.2.6 Fear of Change

This is usually based on ignorance of the objectives and benefits of the proposed changes. [21]. Resistance to change can either be from workers or from management itself. Workers often resist change that may result in affecting their incomes, roles, responsibilities, self esteem and security of employment. [21]. Managers on the other hand resist change if they perceive it as a threat that will erode their authority and if the proposed changes will force them into submitting that non-conformances and poor quality are as a result of their actions.[21]. Hamel [13] suggest that management teams bound by tradition are unwilling to surrender yesterday's certainties, and hence can hold hostage the entire organisation's capacity to embrace the future. [13]. Consequently, management need to distinguish between what is apparently true and what is eternally true.

2.2.7 Lack of improvement skills

A prerequisite for a successful quality improvement program is training in quality-related skills for all employees. [21]. The writer continues to explain that this creates a common language and understanding the means to facilitate improvement. Such training must be open-ended and continuous. [21]. Juran [16] advocates for 'unity *of language …….. in the interest of precise communication'* so that definitions are uniform throughout the organisation.

2.2.8 Lack of Information

What makes the quality improvement process effective is availability of relevant, reliable, accurate and objective information. [21]. Nacelles and Dale [21] have defined three systematic quality improvements:-

a. No measurement without recording
b. No recording without analysis
c. No analysis without action.

This translates to ensuring that whatever data the organisation collects must give feedback to the system so that it can be improved.

2.3 Getting Inspiration: The Quality Gurus

The collective wisdom of the quality gurus, their teachings and philosophies can provide necessary inspiration and guidance to organisations in introducing, developing and embracing a process of continuous improvement. [11]. A brief review of quality management experts' views will be done here focusing on Crosby (1979); Deming (1982), Feigenbaum (1991), Juran (1989), Imai (1986), Ishikawa (1985), Shingo (1986) and Taguchi (1986). [11]

2.3.1 Crosby, P

His focus has been on top management by stressing increasing profitability through quality improvement because higher quality reduces costs and raises profits. [11]. Crosby's programme has 14 steps for organisational transformation and is based on four absolutes of quality management [9], [10], [11]. The four absolutes are summarised below:-

- Quality is defined as conformance to requirements not goodness.
- The system for achieving quality is prevention not appraisal.
- The only performance standard for quality is zero defects not acceptable quality levels.
- The measurement for quality is cost of quality.

2.3.2 W. Edwards Deming

He is accredited as the master who developed Japan's '*road map*' to quality. [17]. Deming's argument, according to Dale [11] is that quality must be achieved through a reduction in variation which will then improve productivity. Kolarik [17] refers to this as meaning process stability and system changes that require understanding and proper use of quantitative tools. The Deming chain reaction links quality, productivity, market share and jobs. Deming's management philosophy is summarised by his 14 point approach. [7], [17]. The two writers also highlight the Deming Cycle or PDCA cycle (Plan; Do; Check and Act) as having received wide application in many quality activities and training programs.

2.3.3 Joseph Juran

Like Deming he has been a major architect of Japan's quality success story. [11][17]. He emphasises the cost of quality, because the language of top management is money. It is important to identify quality improvement projects and opportunities, and to measure quality cost. [11]. According to Kolarik [17] Juran's philosophy for quality assurance is based on the trilogy of quality planning, quality control and quality improvement.

2.3.4 Armand V. Feigenbaum

He has had a great impact on quality management through his total quality control concept and strategies. [17]. Organisations must ensure integration of quality development, maintenance and improvement that will ensure that quality is designed, built, marketed and maintained at the most economical cost which delivers full customers satisfaction.[11][17]. Quality leadership is essential and hence management must commit themselves to strengthening quality improvement, making quality and minimising costs. [11].

2.3.5 Imai

Emphasised the concept of Kaizen as the key to Japanese success story [20] while Dale [11] says of him '*is the person accredited with bringing together the various management philosophies, theories techniques and tools which have assisted Japanese companies………to improve their efficiencies.'* Kaizen is Japanese for continuous improvement and does not mean quality improvement instead it is the process of small incremental steps that give rise to systematic gradual, orderly and continuous improvement" [11].

2.3.6 Ishikawa

He is accredited for three main areas which are simplification and advocacy of seven basic quality control tools, company-wide quality movement and quality circles. [11]. Kolarik [17] highlight his contribution in quality planning and quality function deployment techniques i.e. understanding true quality attributes, being able to measure them and discovering substitute quality characteristics.

2.3.7 Genichi Taguchi

He emphasised an engineering approach to quality. [21]. Taguchi looks at variation as noise and identifies three distinct types of noise; external noise, deterioration, internal and unit-to-unit noise. [21]. Taguchi promotes three stages designing quality:

- system design i.e. functional design
- parameter design i.e. improving performance and reducing costs without addressing causes of variation
- tolerance design i.e. reduce variation by controlling causes.[11], [21]

2.3.8 Shigeo Shingo

Shingo proposed the Poka-Yoke or mistake-proofing system for defect elimination. Zero-defects is the measure of conformance to specification. [11], [21], [27]. Shingo outlined four fundamental principles on which Zero Quality Control is built:

- use source inspection
- use 100% source inspection instead of sampling methods
- minimise time for corrective action when abnormalities occur
- have mistake-proofing devices. [21].

Dale [11] summarises the point of convergence of thinking of the gurus as:

- importance of top management support and participation
- need for work-force training and education
- careful planning and company-wide involvement and
- permanent and on-going improvement activities.

2.4 Human Issues

2.4.1 The human factor in the experience of quality

It is important to understand human needs that relate to quality. Bottlenecks to human performance are primarily lack of effective leadership and lack of creativity with the individual. [17]. Human performance is a very vital factor if the organisation wants to develop and maintain a competitive advantage. Human needs according to Kolarik [17] drive the individual quality experience (IQE) model, figure 2 below. The model has the observation, assessment-interpretation, attitude and behaviour phases. The production of goods and services requires cooperative effort and this can be established through common purpose, individual willingness and interpersonal communication.

A common purpose gives direction and focus and will then define a set of goals, objectives and set targets. Willingness looks at the commitment to cooperate. Organisational effectiveness is the ability of an organisation to accomplish the purpose. In a nutshell the leadership must formulate the vision, define purpose and then build willingness among its members. [17]. What follows after this is for managers to plan, organise, control and allocate resources so that organisational objectives can be achieved through cooperative efforts.

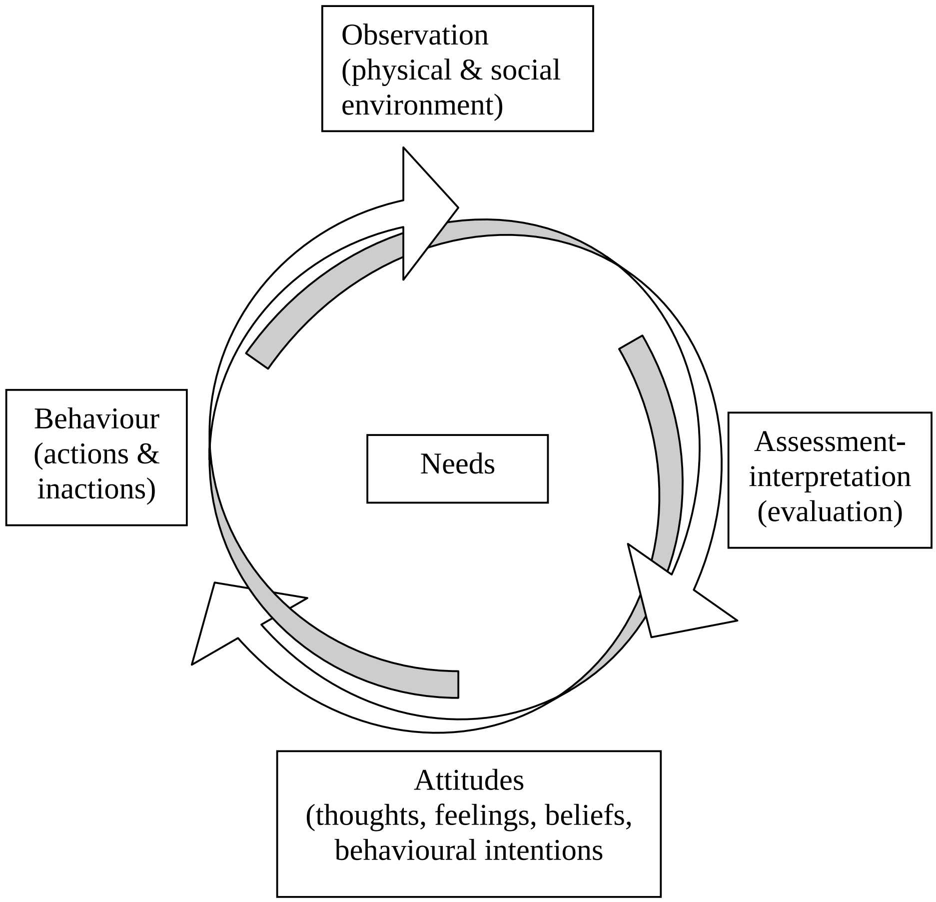

Figure 2: Experience of Quality Concept: IEQ Model (Source: [17])

It is critical to keep staff morale high especially for small and growing businesses where the performance of one unmotivated worker can have an impact on the bottom-line. [25]. Randall [25] has explored needs-driven expectations which if addressed, productivity and efficiency are expected to increase:-

- Need to feel good about ourselves: give genuine praise for achievements, delegate meaningful work, provide workers with challenges and ensure workers understand the impact of their work on profits;
- Need for a good social experience: provide an environment where they can interact e.g. provide free coffee or tea;

- Need for job security: keep workers informed i.e. incapacitate the rumour mill and share with the workers both good and bad news, guard your credibility i.e. do not rush your decisions, small incentives that work e.g. a pizza for staff working late to meet an urgent order;
- Need to produce quality products: recognise quality work and comment on it, be available for your staff, involve the workforce in decision making and they will own both the problem and solution.

Most employees see quality as akin to personal satisfaction and are deeply concerned with accuracy and precision of their work [25].

According to Juran [16] human performance is subject to errors and most of them are due to inadvertence, lack of technique and bias. Human-conscious error can be reduced at managerial level for example by using the redundancy concept in which a jury of opinion check out critical estimates. [16].

Managerial decisions can have an impact on how people perform their duties. Bureaucratic organisations have little or no room for passion, ingenuity and self-direction; they normally give an upper limit on what individuals are supposed to bring to their jobs. [13]. Hamel [13] also suggest that companies organised more like communities unlike hierarchy tend to get more out of their workers because communities amplify human capabilities. People are drawn to the community by a sense of shared purpose, opportunity to contribute to the job, peer-based control and emotional satisfaction.

2.4.2 Management Innovation

Management innovation changes how managers do what they do; it is a departure from traditional management principles, processes and practices. It must create long-lasting advantages when *“it is based on a novel principle that challenges management orthodoxy; it is systemic i.e. encompassing a range of processes and methods; and it is part on an ongoing program of invention, where progress compounds over time”* [13] Hamel [13] also suggests that a systematic process for producing bold management breakthrough must include:

- commitment to a big management problem
- novel principles that illuminate new approaches
- a deconstruction of management orthodoxies and
- analogies from atypical organisations that redefine what is possible.

2.5 Tools and Techniques

Tools and techniques are essential ingredients of a process and '*are not a panacea for quality problems but rather can be seen as a means of solving them.'*[3]. Key factors when selecting tools and techniques to address issues include that:-

- they should be capable of meeting purpose or reason for application.
- users need be trained to a level of competence that make them comfortable to apply and the tolls and techniques effectively.
- determine the successes of the tools and techniques form the results of its application. [3].

Basu [3] has identified four key factors that can present problems when applying tools and techniques:-

- inadequate training
- management commitment of resources
- employee mindset
- poor application

2.5.1 Measurement Tools

Measurement is very critical and ensures that:-

- data collected can map the current performance of the process.
- enables setting of specific goals or standard for improving the process
- process capability demonstrates a quantitative method of how well the current process meets the performance standards. [3].

There are a considerable number of tools and techniques available but the following will be considered for this discussion:

- Checklists
- Flowcharts
- Failure Mode and Effect Analysis (F.M.E.A)
- Statistical Process Control
- Quality Circles
- Mistake Proofing (Poka-Yoke)
- Root Cause and Failure Analysis
- Quality Function Deployment
- Pareto Charts

No one tool or technique is more important than the other. [11]. Basu [3] support this when acknowledging that the sum total of a number of appropriate tools and techniques create sustainable benefits for the whole organisation.” Tools and techniques serve a variety of roles in continuous improvement;

- data collection and provide a summary
- structuring ideas
- identifying relationships
- discovering and correcting root causes
- identifying and prioritizing problems for improvement
- planning monitoring and control of processes
- performance, measurement and capability assessment. [11].

From the above, Basu [3] reckons that, employees using them feel involved; enhanced teamwork through problem solving, facilitate a mindset of quality culture and provide communication medium effective at all levels.

The following gives a brief summary for each of the tools and technique enumerated earlier:-

Checklists: a simple and convenient recording method collecting and determining the number of occurrences.

Flowcharts: process mapping or modelling, provides a diagrammatic representation of all stages in a process by applying established symbols.

Pareto Charts: coined after Wilfred Pareto who observed that 80% of the effects result from 20% of the causes. It is a form of a bar chart that ranks problems starting with the highest to the lowest.

F.M.E.A: a systematic and analytical approach applied at the design, process and service stage of a product, assessing what could go wrong and finding solutions to eliminate or mitigate possible problems. This method was originally developed for the aerospace industry in the 1960s, and in 1972 Ford Motor Company applied it to analyse engineering design. [3].

Mistake Proofing or Poka-Yoke: this technique was developed by Shingo and it aims to prevent errors being converted to defects.

Statistical Process Control: this refers to management or control of processes using statistics. The values are compared against target values which will determine to what extent process parameters can be adjusted.

Quality Circles: shop-floor supervisors and workers who meet regularly to discuss quality issues and help train each other in quality control techniques with the motive of improving quality.

Quality Function Deployment, QFD: it incorporates knowledge about the needs and desires of customers into the design, manufacture and delivery stages and support of products and services.

5S: is a tool for improving housekeeping within an operation.

Seiri – sort (organisation)
Seito – set in order / stabilise (neatness)
Seiso – shine (cleaning)
Seiketsu – standardise
Shitsuki – sustain (discipline).

5 Why: is a systematic method of asking the question 'Why?' five successive times or even more with the aim of wanting to get to the root cause of the problem.

2.6 Assessing the Quality System using Employee Surveys.

The quality system is the base that supports the company processes and hence assessments ought to be carried out for the purpose of improvement. [7]. Quality system assessments normally use two tools:

- Employee surveys: - aim to understand the degree to which the interviewee perceives the expectations of the quality system from him/her in accomplishing organisation objectives.
- Audits then seek to establish if the various elements of the system are well suited for attaining pre-set quality goals. [7].

Employees often find it easy to speak to an outside facilitator than their own boss. [25] Employee surveys will normally use a questionnaire which will focus on:

- the role of management
- the company's values
- the human/social system which tackles issues of motivation, involvement, utilisation etc. [7].

Specific issues that come in the questionnaire relate to:

- attitudes to improvement
- leadership
- dissemination of policies and goals
- recognition
- training

The purpose of the survey must be made clear. Conti [7] explains that it must be explained in terms of *"what it is not"* and then *"what it is."* Employees must assist the company understand if the quality system meet the expectations of its users [7].

2.7 Errors and Quality

Crosby [9], [10] has declared that Zero-Defects is the quality performance standard. Most firms will always accept that errors are inherent in the processes thus they always build in a margin of error either on shipped-product quality level (SPQL) or acceptable quality level (AQL). Conventional wisdom says errors are inevitable [9]. The notion that people as humans are susceptible to make mistakes is erroneous and misleading. Mistakes are not the qualification to be human beings. Mistakes according to Crosby [9] [10] result from lack of knowledge and attention. When people commit themselves to pay attention to detail and avoid errors, they will have taken a giant step to break from traditional values and move towards Zero-Defects. [9]. It is from errors that we end up with defects. These two have a cause-and-effect relationship. It is therefore important to clearly distinguish between an error and a defect. [27]

2.7.1 Defects

There are two major types of defects classified either as isolated defect i.e. those occur either once or at very spaced intervals and serial defects which occur repeatedly. Shingo [27] gives five situations in which defects many arise:

- Inappropriate standard work processes or inappropriate operating procedure established at planning stage.
- Actual operations show excessive variation even though standard methods are appropriate.
- Raw material damage or variation e.g. in thickness.
- Defective tooling or standard devices in the planning stage are flawed.
- Inadvertent errors by workers or machines.

2.7.2 Self Control

Responsibility for contact should be assigned to individuals. Responsibility must be tied with authority. [16]. Juran [16] urges managers to accept that errors exist and hence need to understand the nature and extent of such errors. *"Most errors occur because the criteria for self-control are not met."*[31]. Wollschlaeger [31] has indicated that Juran [16] does not share the belief that lack of motivation by the workers can cause errors. The criteria for self-control are listed as:-

- Knowledge of what is supposed to be done or what the goals are,
- Knowledge of what is actually happening or the performance i.e. establish a system and frequency of measurement and means for interpreting measurement and
- Means of regulating what is happening in the event that goals are not being met. [7], [16], [31]. Juran [16] further explains that workers must be provided with a process that *'is inherently capable of meeting quality goals and with features that enable the work force to re-adjust the process as needed to bring it into conformity.'*

2.7.3 Hindrances to Self-Control

a. Lack of real-time measurement: - Worker prefer real time information about the processes they do and this calls for the means of measurement to be made available on the work floor.

b. Lack of Data Analysis: - This helps create trends that can help the workforce get early warnings of an impending problem. The relationship of the process to the product results has been helped by radical changes in the systems for measurement data collection and analysis. [16].

c. Lack of Adjustment Capability: - A predictable relationship which is precise must exist between changes in the process and the amount of effect on product features. [16}.

2.7.4 Poka-Yoke System

Poka-Yoke is Japanese translation of “mistake-proofing” or “fool proofing mechanism”. These devices prevent components being processed incorrectly or faulty components getting their way to the next operation [18]. Defects ought to be identified before further value is added and they ensure only defect-free components are passed on to the customer. Some of the basic characteristics of Poka-Yoke devices according to McKellen, [18] are simplicity, maintenance free, cannot fail or wear, cannot be removed or deactivated and are low cost and economical. Mistake-proofing devices are best specified at the design stage of the process or component. When deciding on where to place mistake-proofing devices decisions may be based on either costs or those areas prone to mistakes. [18].

Where they are used; poke-yoke devices and not the operator inspect the product [28]. Mistakes become very obvious. The operation will not be completed until the defect-free condition is satisfied. It is important to make poka-yoke the corner-stone of any manufacturing based quality system. [18]. Processes create defects hence management have an obligation to change the processes so as to eliminate defects. [5]. A poka-yoke system has two distinct functions which are to carry out 100 percent inspections and provide feedback and actions in case of abnormalities. [18]

Smith, [28] further asserts that poka-yoke devices are best implemented in a team environment, involving shop-floor operators and their supervisors, engineering and the voice of the customer. [28]. This approach, Smith [28] regrets is not often used, instead it is the engineers and managers who force-feed and spoon-feed it to the shop-floor. If mistake-proofing is not implemented in a team environment, it is more likely to meet with stiff resistance and will fail to meet its initial objective of process improvement.

Successful poka-yoke devices are the ones implemented with the cooperation of workers. Workers buy-in is crucial because:

- They work with the process all the time and are highly knowledgeable about it.
- They are aware of defects that result from errors.
- They experience the frustration of producing the defects.

The engineer’s role should be one of assisting the workers initiate ideas on developing poka-yoke devices and helping them to implement the ideas. The engineer should not have an illusion that they have a monopoly for knowledge; brilliant ideas will come from very unlikely sources.

2.8 Inspection Methods

Inspection of composites is a very complex process. The purpose of quality control is to detect defects that may occur during either manufacturing or repairs. [2]. All components need to maintain the same level of quality and structural integrity specified in the design. Composites are very sensitive to the nuances of the manufacturing process. [2]. Composites have unique characteristics but defects and flaws that occur during manufacturing can adversely affect both the fibre and the matrix. Typical flaws include construction and material flaws, material limitations and adhesion failures. [24]. These problems are responsible for a change in mechanical properties and in some cases to levels below the design allowable criteria. Inspection is performed to detect porosity, voids, presence of foreign materials, excessive adhesive, crushed and misaligned honeycombs etc.

This discussion will focus on three main types of inspections:

1. Judgment Inspections;
2. Informative Inspections and
3. Source Inspections

2.8.1 Judgment Inspections

These are inspections that discover defects. This is the post-mortem type of inspection focused on finished goods. The goods are classified as either acceptable i.e. pass or defective i.e. fail. The method ensures all defective goods are not delivered to the customer or do not proceed to the next process. It does not and will not add to the reduction in defect rate regardless of how thorough or accurate it is conducted.

Inspections do not reduce defects they only discover them because most if not all are carried out at the very end of the process. Defects on the other hand occur during the process and hence it is critical to use processing methods that ensure defects will not occur in the first place. [27]. Shingo [27] has explained that mistakes that result in defects can be engineered out of the process in order to eliminate the defects.

2.8.2 Informative Inspections

These are inspections that reduce defects. They revolve on initiating rapid response and feed-back to the work processes involved as soon as a defect is detected. There are three main types which are:-

a. Statistical Quality Control Systems

b. Self-Check Systems
c. Successive Check Systems [27]

i) Statistical Quality Control System (SQCS):

This is informative inspection that relies on statistical information and control charts to reduce defects. Information on defects is relayed back to the offending processes from the analysis of the control charts, and this consequently results in changes being made to the work process or method. Statistics are used to set the normal and abnormal limits and also to determine the number of samples used to establish abnormal values. [27].

It should be noted that control charts serve as mirrors that give the status quo i.e. the as-is situation. They do not guarantee any improvement in quality unless real corrective action is taken.

Abnormalities and irregularities do not take a predetermined fashion, they occur randomly. It should be noted that there is always a time lag between the discovery of abnormalities and when corrective action is taken. This mean time before improvement (MTBI) may with no doubt allow defects to pass through the system.

ii) Self-Check Systems

This is also called self-inspection. In this system of checks, the same worker who is involved in doing the work also carries out 100 percent inspection. Although self-checks present an opportunity for rapid feedback and swift corrective action, they suffer two main disadvantages:

- Human tendency is always to compromise on work they will have done themselves
- Chances of forgetting to carry out checks are real. [27]

This relates to the role the worker plays in ensuring product-conformance. When workers carry out product-conformance decisions it means they are deciding the product's next destination. [16]. Juran [16] acknowledges that traditionally this has not normally been delegated to workers, but independent inspectors and checkers. With a change in this thinking, a pre-requisite for the criteria are:

- quality must always come first
- mutual confidence and trust between management and the workforce
- workers must be in a state of self-control
- training; workers must be trained and confirmed capable to perform product conformance decisions. [16].

iii) Successive Check System (SuCS)

When applying successive check system, each successive worker inspects work from the previous process independently. If defective components are detected, they are passed back to previous process for rectification. The line is summarily closed to ensure that no further defective items are made before corrective action is done to the process or work. This is to be done by workers themselves. [27]

The effectiveness of this method comes from the fact that inspection is actually done by other workers rather than the one who did the work; inspection is 100 percent and feedback and corrective action is expedited.

It should be noted that the initial stage of successive checks results in an increase in the number of defects. These defects can be classified as in-process and final process defects. In-process i.e. those that occur between processes increase due to the discovery of defects which used to pass on to the next process stage unnoticed. Final process defects i.e. those found at the process' final inspection decrease significantly. [27]

iv) Source Inspection

This is the inspection that eliminates defects. With source inspection, focus is to reveal errors that result in defects so that the feedback and action targets error elimination. As a result these errors are never allowed to turn into defects. [27]

Source inspection is broadly classified into vertical and horizontal source inspection. Vertical source inspection involves controlling processes upstream if they contain cases of defects while horizontal source inspection is concerned with defects within processes and ensuring inspections inhibit errors from becoming defects. [27]

Poka-Yoke devices if used in combination with source inspection and 100 percent inspection, feedback and corrective action are rapid. It is under these circumstances that Zero Quality Control Systems can be achieved.

2.8.3 Inspection Techniques

Inspection techniques are broadly divided into non-instrumental non-destructive inspection (NDI) and instrumental non-destructive inspection. [14]

i) Non-Destructive Instrumental NDI

Visual Inspection: - This is the most commonly and widely used technique at the moment. Visual inspection makes up 80% of all inspections in the aviation industry while the CAA put the figure at 90%. [24]. Defects are often larger than they appear under visual inspection and hence further NDI to ascertain the extent of cracks or subsurface damage is necessary. [14]

Audiosonic: - also called tapping is very subjective in its interpretation. It is capable of detecting disbonds or delaminations of thin skin in sandwich structures and outer plies of monolithic structures. [14]

ii) Instrumental NDI Technique

Ultrasonic: - This is by far the best method to locate and identify damage on monolithic components. [14] Pulse-echo and through-transmission methods can be used to inspect sandwich components for disbanding. C-scan pulse-echo method is used for mapping from only one side. [14]. In this instance the operator is assisted by techniques that enhance the opportunity for detecting small and hidden defects. [24]. Other methods include penetrants, moisture meters, X-ray radiography, mechanical impedance and thermography.

2.9 Methods of collecting data

2.9.1 Questionnaire

a. What is a Questionnaire?

The term questionnaire refers to a set of questions carefully worded that is used as an instrument of research or a tool of data collection. A questionnaire can be used to cover postal questionnaire, group or administered questionnaire, structured or telephone interviews and is also used to include checklists, attitude scales, projective techniques and rating scales. [23]

This method of collecting data is one of the most widely used and the questions are prepared well in advance together with the response categories. It is least expensive although it can be used to reach a wide range of respondents. [30], [26]. The researcher must be clear of the questions to ask. It is quick to use the questionnaire method when you compare it with other methods of collecting data. [26]. Response rate for questionnaires is generally very low although it can also depend on the issue under investigation. In coming up with the questionnaire, importance will be paid to the structure and degree of literacy of some of the respondents and appropriateness of language.

In building a questionnaire, the following general considerations need to be taken into account:-

- Method of data collection:- this includes instruments such as interviews, postal questionnaires, content analysis of records, observational techniques etc;

- Method of approach to respondents:-it focuses on sponsorship, stated purpose of the research, length and duration of the questionnaire, confidentiality and anonymity;

- Build-up of question sequences, ordering of questions and scales;

- Type of questions to be used e.g. closed questions etc. [23]

a. Format of Questions:

i. Fixed-Alternative Question

This resembles an item on a multiple-choice test and respondents have several choices. It generally yields two basic types of data which are normal or qualitative data and interval scale data e.g. strongly agree, agree, disagree and strongly disagree. [19]

ii. Nominal Dichotomous Data Items

Dichotomous questions only allow for two responses either yes or no. If properly constructed, nominal items are easier to answer and score than any other type of questions. The respondent and investigator often have higher chances of similar interpretations of items since there are only two options. Well-constructed dichotomous items often present a highly reliable and valid measure. [19]

One disadvantage associated with nominal dichotomous items is that respondents may resist the fixed alternative nature of questions. Alternatives presented may prevent respondents from accurately expressing their opinions. The investigator is deprived of information about subtle differences among respondents and the ability to find relationships among variables. [19]

iii. Open-Ended Questions:

Open-ended items pose a question with no pre-determined responses. Respondents have more freedom about how they answer their questions thus unexpected but important responses can be received. Open-ended questions allow the investigator to asses the degree of sophistication and knowledge of the survey topic from respondents. This gives the investigator an insight into whether the respondents fully understand the information being sought after. [19]

The main disadvantage of open-ended questions is that they take more time to ask and record. It is time consuming for both the investigator and the respondents. Respondents normally find it difficult to generate their own responses. Generally, creating open-ended questions and recording responses require skills. The most difficult part of open-ended questions is that they are difficult to score. Responses may be so varied that there may not be any obvious method to code them. [19]

b. Likert-type and Internal Items:

The Likert Scale allows the respondents to respond to a statement by choosing one of the following; strongly agree, agree, neither agree nor disagree,

disagree and strongly disagree, with scoring allocated from 5 for strongly agree to 1 for strongly disagree and vice-versa depending on the characteristics of interest. Likert-type items yield more data than nominal dichotomous items and since they yield interval, they can be analyzed using more powerful statistical tests. [19]

As in nominal dichotomous items, Likert-type items also suffer the disadvantages of the fixed-alternative nature of questions.

Results from the Likert-Scale can be added to produce a summary score. The statistical advantages of using a summated score are:-

- A score based on several questions is reliable than a single question.
- Analyses are usually simpler for summated scores. [19]

c. Likert Scales

The primary focus of the Likert scale is to maintain uni-dimensionality that is they ensure that all items measure the same thing and the need for judges is eliminate. Items are thus planned on an attitude scale from strongly agree to strongly disagree. The Likert Scale is produced by first generating an item pool. A sample of respondents is then tried on the item pool. It must be noted that the Likert procedure does not recommend having too many neutrals or too many extremes on either side of the scale. [23]

The record of each respondent is scored. A decision has to be made as to whether a high score is to mean a favourable or an unfavourable attitude. If a high score on the scale is to mean a favourable attitude then favourable statements must be scored 5 for strongly agree down to 1 for strongly disagree, and unfavourable statements must be scored 1 for strongly agree to 5 for strongly disagree [23]

The best available measure of the attitude concerned is the total item pool constructed. Items need to be consistent and homogeneous and must be measuring the same thing. Likert scales generally tend to give good reliability, partly due to a greater range of answers given to respondents.

Criticisms levelled against the Likert Scale include lack of reproducibility, that is the total score can be obtained in different ways. The scale has no metric or interval measures and hence does not have a neutral point thus the change in the middle range scores from mildly positive to mildly negative and vice-versa cannot be ascertained. It must be noted that the neutral point must not be taken as the mid-point of the two extremes. Scores in the mid-range can be due to luke-warm responses, lack of knowledge or lack of attitude as demonstrated by respondents. [23]

There are six steps to be followed in the construction of a Likert Scale

- Compiling possible scale items.
- Administering items to a random sample of respondents.
- Computing a total score for each respondents
- Determining the discriminative power (D.P) of items.
- Selecting scale items and
- Testing reliability. [22]

d. Determining the Discriminative Power.

In this method, determine items that are consistently separated, that is those that are high on the attitude continuum and those that are low. The item analysis subjects each item to its ability to separate the highs from the lows and this is called the discriminative power of the item. Calculating the DP, involves summing the score of each respondent and arranging them in an array say from lowest to highest. Compare the range between the upper (Q) and lower (Qs) quartile. The D.P is therefore the difference between the weighted mean of the scores above Q1 and those below Q3. [22]

2.9.2 Interviews

There are five different styles of interviews that can be used which are structured, standardised open-ended, semi-structured, interview guide approach and unstructured style. [29]. In the structured approach, the questions to be asked, their order and responses are pre-determined. With the standardised open-ended, the questions and their order are pre-determined whereas responses take any shape. The interview guide approach has the interviewer making up the questions at the instance of the interview although the topics for discussion are decided in advance. The unstructured interview is informal, more conversational and neither questions nor responses are determined prior to the interview. [29].

Form the list discussed of interview styles, the standardised open-end has been chosen for use in conjunction with the questionnaire and this is the approach will be used interview the Quality Manager. The questions were formulated so that in terms of their content they had a common footing with the questionnaire. The responses were expected to be detailed and it also gives the interviewer a chance to probe further.

The unstructured interview approach was used together with the observation process. This became appropriate because of the researcher’s interaction with the laminators during the course of their work.

2.9.3 Observation

The observation method of collecting data involves watching and recording events as they proceed and this may entail how people behave or listening to verbal interaction. [26]. [30]. The purpose of observation is to gather knowledge about specific issues. Distinct features about observations in research are the manner in which the observation itself is organised, recorded, interpreted and used.

The advantages of using observation as a data collecting method include that:

- The researcher is able to record real-time information on the human behaviour and the environment rather than relying on third parties whose information may be inaccurate,
- The observer is able to take notice of things participants often take for granted or as the norm,
- The observations can also serve to represent the data of those who may not be able to express their views for a number of reasons e.g. because they do not have time, they are unwilling to participate or do not want to risk the consequences for giving their views and
- Data from observations can be used to validate data from other sources. [26].

Despite the advantages given above, observation also has its own limitations. The environment, event or behaviour of interest may not be readily accessible. For the simple reason that they are being observed, people may change from their normal behaviour. Critical to observations is that it may suffer observer’s bias which may mean that what we get is not a representation of reality. Observational research is very time consuming. [26]

2.10 Chapter summary

This chapter has reviewed literature deemed relevant to Lola’s quality problems. It presented an overview of issues that need to be considered in quality management especially with regard to manual processes. The literature looked at the various ways in which quality is perceived and came out with a working definition of quality with regard to Lola. The barriers to continuous improvement have been explained focussing both on management and the work force. It is when these barriers are overcome that an organisation may start to realise meaningful changes to quality initiatives.

Composites manufacturing at Lola is a highly manual process and hence there are a lot of human interactions with both the product and the processes. It was therefore critical to evaluate the effect of the human element on product quality and in which way human behaviour can be influenced to avoid or minimise defects that result from errors. The other part where the human element is critical is in visual inspection which apparently account for between 80% and 90% of all the inspection in composite manufacturing.

There has been an insight into the tools and techniques that may be used or applied for collecting and analysing data as well as analysing problems when they occur. Inspection methods where reviewed highlighting their benefits as well as disadvantages which can then assist in coming up with an inspection organisation that can minimise defects. Although there are a variety of inspection techniques used, visual inspection and ultrasonic inspections seem to be the most predominantly used.

3. Methodology

3.1 Introduction

This chapter describes the method used to gather data and generate information for analysis, setting the ground clear for a better understanding of the problem and also making it possible to address the objectives identified for this research. This section therefore covers three distinct areas which have been selected based on an extensive literature search covered in chapter 2. The methodology for the research will therefore focus on:

- data collection
- questionnaire survey to understand attitudes towards quality and
- observation of the lamination process.

3.2 Data collection

The main purpose of data collection is to validate the as-is scenario, highlight areas of concern then focus and direct improvement initiatives and efforts on the process flaws that adversely affect the product quality.

Trends need to be established as to whether Lola has adopted continuous improvement and Total Quality Management (TQM) as its business ethos. Chronic problems will be identified and then preventive and corrective mechanisms will be devised that can be applied to them. The choice of tools to analyse the data and also carry out diagnosis is very important.

3.2.1 Historical Quality Data

Historical quality data refers to any data or statistics that Lola collects or generates as process indicators or performance indicators of the product until it gets to the market. Data collected for these two areas will give a good picture of the company's quality performance in the past which must then be the building point for any improvement initiatives. The data that is of interest that focuses on internal quality problems and impact on the yield is scrap and reworks while that giving external quality problems is evidenced by customer rejects and complaints.

3.2.2 The Quality Management System.

The alignment of improvement initiatives to the overall strategic objectives is critical. Management need to put in place an enabling environment that will help workers recognise how and where these initiatives fit in the overall objectives. To this end it is important to understand what powers Lola's quality programme and where in terms of Total Quality management we can place them. Management responsibility to quality will therefore be analysed in relationship to the following criteria which are the milestones of a QMS:-

- Management Commitment
- Customer and supplier focus
- Quality policy
- Quality planning and responsibility

3.3 Quality Attitudes Survey Questionnaire

The questionnaire targeted representation across the whole organisation thus putting focus on all stake-holders. The main stakeholders in this instance are senior management, middle management, personnel from the Quality department, and the general workforce from various departments at Lola.

The purpose of the questionnaire will be to determine the following:-

- to establish if there is a common understanding of quality across the organisation,
- determine attitudes towards quality and continuous improvement and how well the message of poor quality is spreading across the organisation,
- establish if the various strata or levels of employees understand their roles on the quality journey.

It needs to be established if the whole organisation has a common understanding of quality issues. Is everyone looking at quality issues in the same way and with the same intention i.e. to continuously improve it? The focus of the questionnaire on management was to evaluate its commitment to quality by way of doing. Management also had to indicate if they had won an employee buy-in to the quality focus. Workers are responsible for executing the process thus their understanding of the expectations on quality is critical. Issues raised in the questionnaire can be summarised as follows:-

- general understanding of quality
- human-related issues
- cultural issues
- cost of quality
- suppliers and customer issues

For each question there were five responses categorized according to the Likert scale, Table 2, described in the literature.

Strongly Agree
Agree
Hmmmm, i.e. doubtful
Disagree
Strongly Disagree

Table 2: Questionnaire Categories

A total of 15 questionnaires were sent out across various section of the company. Although this project focuses on the lamination process, the questionnaire was intended to make a survey across the whole organisation. Thus the questionnaire was sent to the following departments:

- management
- lamination shop
- mould shop
- pattern shop and
- trim shop.

To compliment the questionnaires, arrangements will be made to conduct one-on-one interviews with senior management whose responsibility is linked to quality.

3.4 Lamination Process Observation.

It is an important part of the research to observe the process as it occurs. To be able to contribute meaningfully the researcher ought to get involved and understand the situation on the ground. Issues of interest will include:-

- pre-lamination material handling.
- lamination tooling.
- the lamination process.
- in-process inspection methods and techniques.

The approach to the lamination process observation will apply two methods of collecting data which are the case study method and use of unstructured interviews.

3.4.1 The Case Study Approach

The case studies will be company based and will take place during a week-long study visit. In consultation with the lamination team leader, jobs will be identified that can be done and completion within say three to four days so that the issues of interest can be assessed as they are executed by the laminators. The case studies together with their studies will be done earlier than the questionnaire so that the outcome of the questionnaire will not influence the researcher's observations. To gather data that is representative of the status quo, the researcher will guard against the limitations highlighted in the literature review. A record of the events will be made as they occur.

3.4.2 Unstructured Interviews

During the observation process, the researcher will also endeavour to probe the shop-workers by asking questions and having discussions. The unstructured interviews will be based on general quality issues or on other observations not necessarily related to the case studies. The unstructured interviews are targeted to be done midway through the week when the researcher expects to have established good rapport with the shop-floor workers. In this way the natural outlook of these interviews will be established and the respondents will tend to give an honest view to the best of their knowledge. The results of the four areas of investigation will give a bigger picture on issues that affect Lola's quality. The results will then be analysed and recommendations made on:

- both strengths and deficiencies in the current business practices in as far as quality is concerned,
- quality and quality drivers.
- continuous improvement as a strategic business tool.
- tools and techniques that can be applied to problem solving.

3.5 Preventive and Corrective Actions

It is important to understand the approaches used to prevent and correct problems. Two approaches to problem solving will be evaluated. The first will be to establish preventive mechanisms and tools used to ensure possible problems are avoided. The second will look at corrective actions.

Corrective actions will be based on the statistical data collected. Applied correctly FMEA should address preventive actions while Root Cause Analysis must address corrective actions that aim to reduce or eliminate recurrence.

3.6 Chapter Summary

This chapter has discussed different segments of data generated in different ways but all of which is used to give a bigger picture of how quality is understood, organised and managed at Lola. Quality has been tackled from three main fronts, the first being using historical data to interpret Lola's quality attitudes. Certainly if we have a desire to change, this kind of data should guide us. This data is definitely a performance indicator on which management must act so that they reverse the trend.

The understanding of quality by all those players who contribute to it in one way or the other was viewed as important hence a questionnaire was done to examine these attitudes. There were not many questionnaires sent out by virtue of the size of the organisation but the response rate was tremendous at 80%. This was consolidated by the interview done with the Quality Manager.

The lamination process was observed so as to identify potential flaws that affected product quality. Also critical during this stage was to identify opportunities for improvement and those attitudes and behaviour that need to be changed. It is also important from this process to highlight to the operators how their actions can influence product quality. The first section relates to internal data generated from the company. The second discusses the questionnaire that is sent to employees of the company at different levels and interviews conducted with the Company's Quality Manager while the third deals with information gathered from observing the lamination process.

4. Results

4.1 Introduction

This chapter will highlight the findings from the investigation of critical issues that are linked to Lola's quality management. It will evaluate the relevance of data that is collected at Lola for the purpose of analysing quality performance. Attention will also be paid on the tools and techniques that are used to analyse the data and in what way the results of the analysis are used to improve both the process and the product. The information that was gathered from the observation of the lamination process and the questionnaire surveys will be used for furthering the knowledge on the quality problem.

4.1.1 Historical Quality Data

The data that Lola collects has been grouped into two main categories which are internal and external. Internal data that has been deemed to be important when looking at quality problems is the data that is generated under the auspices of the pre-trim non-conformances and these will include:

- Not Right First Time (NRFT) Non-Conformances which incorporates scrap and rework
- Laminator defects analysed in conjunction with the skills matrix.

External data on the other hand focuses on Post-Delivery Non-Conformances, mainly focusing on customer complaints and rejects.

4.1.2 Not Right First Time Non-Conformances.

Any product that does not pass the inspection at the point it is finished from the processing is referred to as not-right-first-time. Scrap and rework directly reflect how good the lamination process is performing. Data that highlight problems at this stage and which will have an impact on the lamination process include:-

- Laminator defects and the skills matrix
- Inspection criteria data

4.1.3 Scrap and Rework

These failures have been referred to as Not Right First Time, (N.R.F.T.). This gives the quality performances of the lamination process. The graphs below, figure 2 and figure 3, show the scrap and rework for the period 2005 to date and 2003 to date respectively. Trends need to be established and then validated if there is effort being directed towards reducing the N.R.F.T. The trend over the past two years is that scrap rate was very high at the beginning of 2005 progressively decreasing towards year end. There is a reverse of this trend for 2006. Rework rate was very high for year 2005. The parts N.R.F.T. i.e., both scrap and rework, have been compiled monthly for the period 2005 to date and plotted side by side to show the relative ratios of scrape to rework. There is no significant reduction in the total N.R.F.T. When scrap rate was going down rework levels were going up showing that most work that escaped scrapping was recommended for rework. This trend is definitely a cause for concern and it necessitated the collection of data for the period 2003 to 2004 in order to be certain of this see-saw relationship of the N.R.F.T.

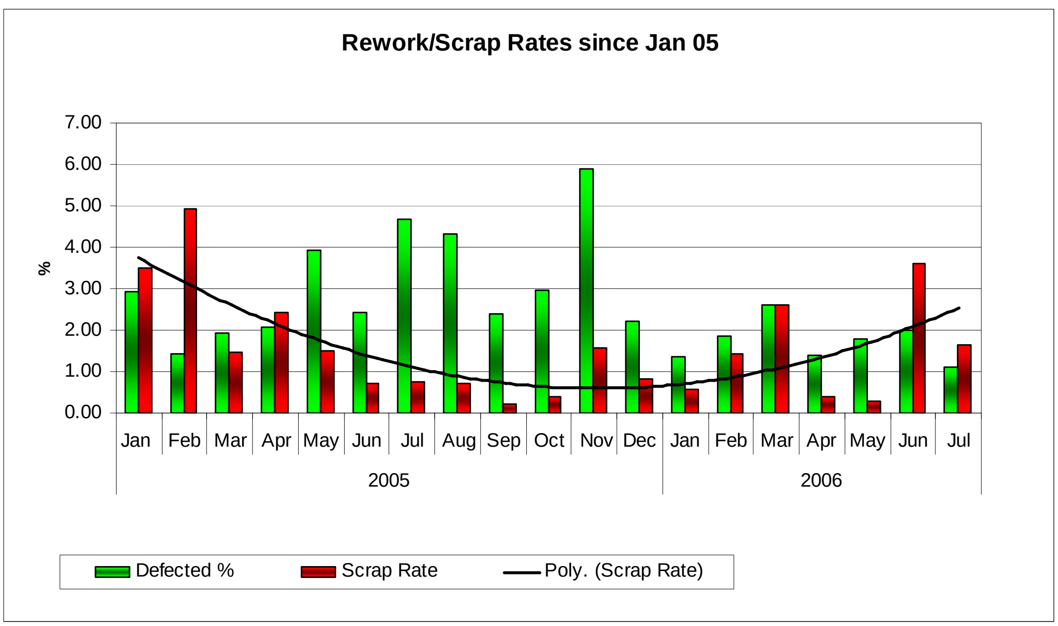

Figure 3: Scrap and Rework Rates 2005-2006. (Source: Internal Data System)

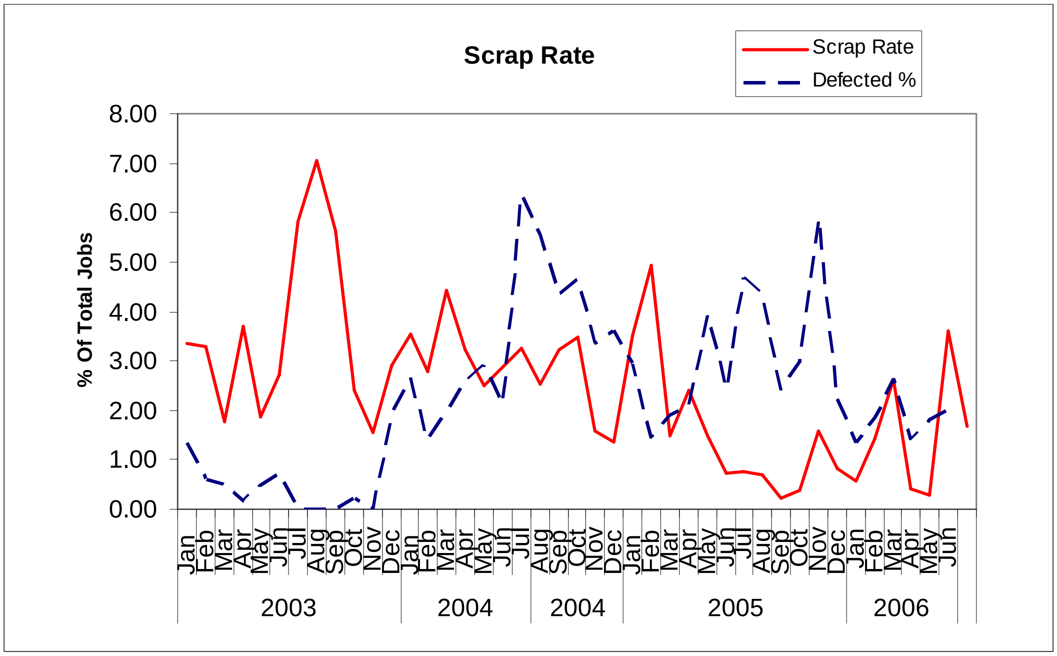

Figure 4: Scrap and Rework 2003-2006

The N.R.F.T.s at the pre-trim stage constitutes about 10% of the total inspected components. It still needs to be noted that numbers in this type of business may be misleading since most of the components are of high value. In order to have a better understanding of the failures, the major causes of N.R.F.T.s have been identified and presented in Table 3. The table covers the period spanning from January 2005 to June 2006. From the table the causes that were responsible for 80% of the problems come from material bridging with 51%, documentation incomplete with 16% and unidentified items with 13%. Just looking at the table, the unidentified group immediately becomes a cause for concern. The unidentified items are among the group that constitute 20% of the causes. This now calls for these items to broken down further so that so that every component of the causes is identified into its respective category. It should be noted that at Lola, when they represent the figures in Table 3, they do not include component identification and documentation incomplete on the pretext that they do not directly affect quality.

On the contrary, they do. It is quite strange that a part of the problems that has featured so much both for pre-trim N.R.F.T. and also been captured by the PCAR's can be left out without being addressed. If everyone is convinced that it is a minor problem and has no effect on quality, then let it be solved. However, in this study they have been handled collectively because within the QMS they are non-conformances.

Pre-Trim N.R.F.T.	**Sum**	**NRFT %**
Component identification	3	1%
Documentation incomplete	63	16%
Drilled Holes	17	4%
Material lay-up must maintain full thickness to EOP	23	6%
Material Bridging	202	51%
Damage to component	17	4%
Flatness	6	2%
Steps in tooling/ material Pinch-up	2	1%
Weight variation	3	1%
Inclusion of foreign objects	3	1%
Heat foil	0	0%
Defects transferred from tooling	1	0%
Synspan bleed through onto visual surface	0	0%
Neatness of first ply	3	1%
Unidentified	50	13%
NRFT	**393**	**100%**
NRFT as % of Total Inspected	**10%**	
Total inspected	**3988**	

Table 3: Pre-Trim N.R.F.T. Defects

4.2 Root Cause Failure Analysis (RCFA)

The root causes of a problem are the origins of a chain of events leading to the problem itself. While the Pareto chart will be the most convenient tool for identifying the 20% of causes that account for 80% of the effects, for this specific situation, it is very clear and will not require that detail. Material bridging is certainly a major issue and will need to be addressed. Material bridging refers to the manner in which laminates are overlapped to form to form a joint. There are differences in opinion regarding this problem. Although the Quality department insisted that the problem is indeed material bridging, processing maintained it was not although they would not say what it is. Thus this problem was taken as material bridging.

It must be noted that in order for correct solutions to be implemented all concerned parties must agree as to the nature of the problem. The purpose of analysing data is to ensure that a common understanding is reached.

4.2.1 Preventive and Corrective Action Request. (PCAR)

Lola devised the preventive and corrective action report form whose main purpose is to encourage use of the tool by everyone in the company in identifying problems and opportunities for improvement across the business. Its wide business focus avails to everyone an opportunity to raise it if they have issues they feel need attention. This was designed to aid employees' efforts in problem solving. Items that have been raised in the PCAR which are critical to quality include:

- scrapped and reworked components and tooling
- customer complaints and rejects
- customer rejection of tooling
- audits non-conformances
- request for concessions or additional information from customers
- actions necessitated by FMEA

The PCAR, therefore, must be capable of correcting problems and preventing recurrence.

PCAR CATEGORIES	Count of Occurrence	Percentage	Cumulative
E: Scrap (Production)	605	28%	28%
N: Audits	350	16%	44%
M: Internal Customers	211	10%	54%
A: Customer Reject	160	7%	62%
K: Suggested Improvement	139	6%	68%
B: Customer Complaint (Delivered item)	105	5%	78%
F: Rework (Production)	83	4%	82%
L: Information Request	76	4%	86%
D: Rework (Tooling)	75	3%	89%
Z: Other	65	3%	92%
I: Concession Request	50	2%	95%
J: Health and Safety	24	1%	96%
Q: Maintenance	20	1%	97%
R: Request for Equipment	19	1%	97%
H: Schedule (Production)	16	1%	98%
O: Vendor	12	1%	99%
P: Process Job Requests	9	0%	99%
C: Scrap (Tooling)	8	0%	100%
W: NPI Tests	4	0%	100%
G: Schedule (Tooling)	2	0%	100%
S: Five S's	2	0%	100%
Y: Customer Complaint	1	0%	100%
Total Categories	**2148**	100%	

Table 4: PCAR Categories

In the table above, Table 4, the PCAR categories were grouped in descending order and then expressed as a percentage of the total occurrences. They were ranked and the top seven that are responsible for about 80% of the problems identified as opportunities for improvement or areas that require to be addressed. The seven areas are scrap resulting from production, non-conformances from audits, internal customer complaints, customer rejects, suggested improvements, customer complaints from delivered parts and rework in production. Figure 5 shows the Pareto Chart for the same data.

It is a major concern that the audits which are a critical component of the quality management system come second on issues that requires urgent attention. This shows a major weakness in the QMS whose main purpose is to identify non-conforming components of the manufacturing system. On most of the PCARs addressed, most of which are directly linked to product quality, corrective action is generally done by individuals, There is no evidence of teams being involved in solving the problems highlighted and neither is there proper root cause and failure analysis that should make it certain that recurrence of some these problems addressed is not likely.

The PCAR meetings as given in the current guide for use if adopted in its entirety will turn the system into any other exercise. The comment reads “If you do not want to attend, get it done on time!!” For the system to work more efficiently, meetings must be mandatory. There is more to it than just doing and completing a specific assignment. It must be remembered that the PCAR is both a proactive and reactive tool. Other people also need to learn from the experiences of the solution implementers, the good and bad experiences so that when a similar problem arises improved solutions can be implemented. It is worthwhile to mention that the PCAR system is reported to have achieved a success rate of at least 90%.

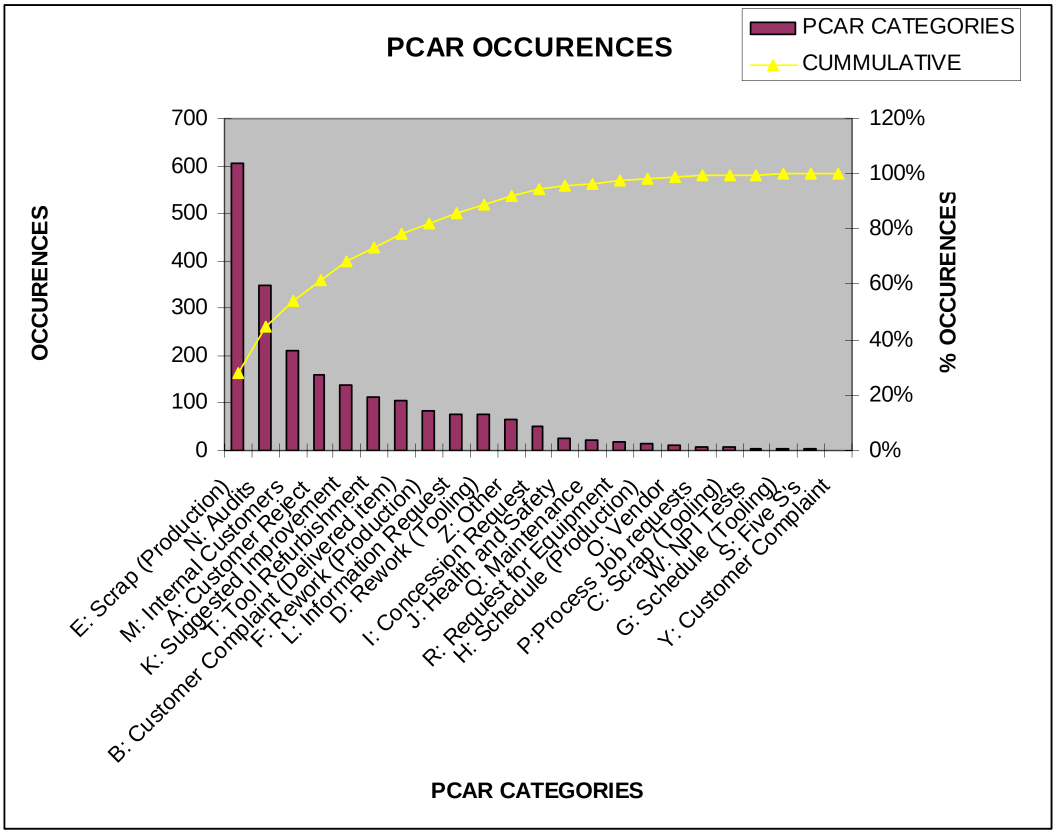

Figure 5: PCARs Pareto Chart

To propagate the PCAR system as an improvement tool, there is need for immediate feedback to all those taking their time to raise the PCARs. Receipt of their PCARs must be acknowledged and given an assurance that action will be taken to redress the situation. If a solution is feasible, the person who has raised the PCAR must be told the person who is going to address the problem and by when. It is also important to ask them for their suggestions in solving the problem. If their suggestion is not feasible they need to be told why. In this way you keep the door open for more ideas.

4.2.2 Open PCARs

These present not only a big challenge to this otherwise noble initiative but also a threat that will undermine the PCAR system completely. This is so because most offenders are the same people who, by virtue of their positions and responsibilities, are supposed to ensure that the system is working. While deadlines will be set in progress meetings, there is no guideline as to the maximum period within which PCARs should be closed. Just a look at the current open PCARS revealed that one still outstanding backdates to October 2005. The time that has lapsed before corrective action was taken to address this issue is definitely in excess of acceptable time limits. Given below in Figure 6 are some of the open PCARS as at 11/08/2006.

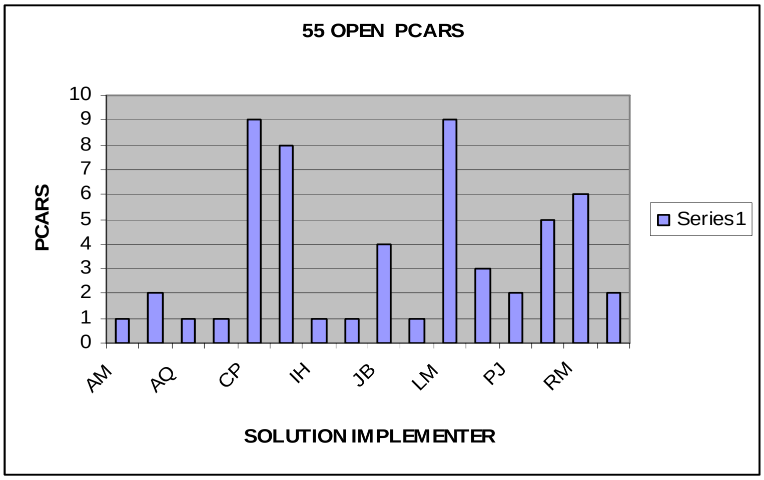

Figure 6: Open PCARs

4.2.3 Post-Delivery Non-Conformances.

This external element of quality evaluation has focused more on customer rejects, customer complaints and concessions. At this level it was important to assess Lola products in terms of conformance to specifications. For this kind of business, volumes may mislead as Lola is a low volume, high value business. Therefore every little bit counts.

Lola issues out a Certificate of Conformance which is raised by the Quality department at the point of delivering the component yet there are still customer complaints and rejects that arise. An analysis of post-delivery non-conformances would challenge the attention to detail of the inspection criteria at the point of delivery.

The customer rejects and complaints for the period from January 2003 to July 2006 are shown in Figures 7, 8 and 9. The general trend for customer rejects has been a decrease in rejects from 2003 until the end of 2004. After the first quarter of 2005 there has been a steady increase in the number of customer rejects and that should be a cause for concern. The gains that had been achieved in terms of meeting customer requirements
are again being threatened. This is shown in Figure 8 below. Customer complaints on the other hand have shown a gradual decline as shown in Figure 9. Customer rejects and complaints have not been analysed by customer because the data lacks completeness and hence lacks credibility for a comprehensive analysis.

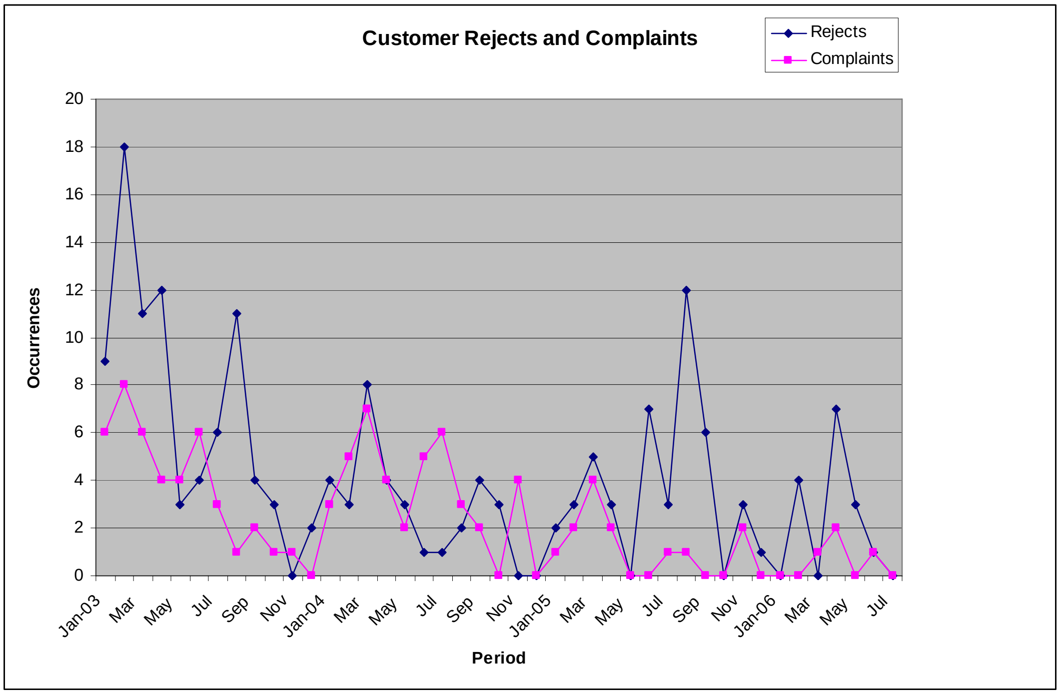

Figure 7: Customer Rejects and Complaints

Figure 8: Customer Rejects Trend

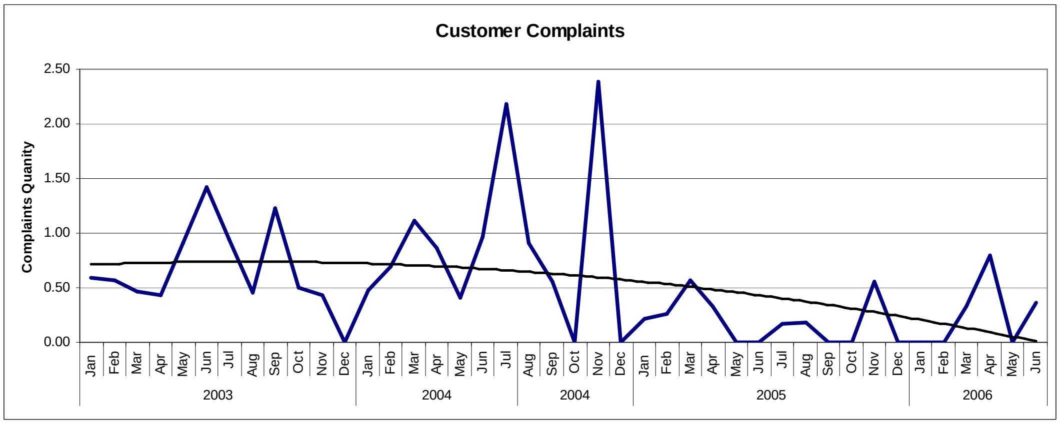

Figure 9: Customer Complaints Trend

4.3 Quality Attitudes Survey

To make an assessment of quality attitudes at Lola, this was carried out in two ways. The first method was to conduct a questionnaire survey and the second was an interview with a management representative and in this instance it was the Quality Manager. The questions put in the questionnaire were exactly the same as the one in the direct interview.

4.3.1 Questionnaire

The detailed questionnaire is given in Appendix 3. This questionnaire was targeted at the full spectrum of Lola and sought responses to five critical issues that relate to quality management which are quality issues, cultural issues, human issues, cost related issues and relationships with our business partners i.e. suppliers and customers. The results of the survey, scored using the Likert Scale, have been summarised as summated scores in Appendix 3. The major concern from the results of the survey is on the percentage of respondents who are doubtful and are not so sure of the direction of the company. Scores above the mid-range have been taken to show a favourable condition while those below will denote an unfavourable condition.

From the analysis, the respondents generally accept that there is a clear and good understanding of quality related issues, that the employees do understand what quality is, have knowledge of the tools and techniques in place for improving quality and are aware of the existence of the QMS. This however is contrary to the opinion given by the Quality Manager who believes that there is a general lack of understanding of quality principles at the company. However the Quality Manager's position on the lack of understanding of the quality management system and quality improvement seem to get the support of the respondents when they acknowledge that sourcing decisions are based on economic grounds and price and not quality attracts more attention. This loss of emphasis on quality has resulted in work commencing without adequate resources to support the work.

Lola does not demonstrate a culture of adopting continuous improvement on its quality. The summated scores relating to cultural issues fall below the mid-range which shows a generally accepted position that both management and workers have not demonstrated positive changes in attitudes towards quality.
Quality culture exhibited by such things as on-going training on quality and continuous improvement, team-based effort against individual effort and discouraging such practices as concessions must become the business ethos.

Employees will perform better if there is recognition for good work. We learnt from literature how motivation can bring about positive contribution. The summated score that is above the mid-range is very critical of rewards or praise for good work or even quality training but there is wide agreement that the company has not institutionalised punishment as a form of discipline.

There is a very good understanding of the significance of costs in relation to quality. There is a general agreement that poor quality has adverse effects on costs and therefore management need to build on this point to widen this knowledge to encompass the whole business. Building on this common understanding the sourcing decisions must be based on quality and not price.

At least a good proportion of the respondents is quite critical of the company's policy on goods inwards from suppliers and acknowledges that supplier quality is not a priority at Lola. This is an area that really needs attention since the quality of Lola's products is heavily dependent on what it gets from its suppliers. The respondents believe that there is no customer focus. Quite astonishing is the fact that the company does not understand its customers' expectations with regard to quality especially when Lola has defined quality as conformance to requirement in its quality manual.

4.4 Interview with Quality Manager

A one-on-one interview with a management representative was done with the Quality Manager, Terry Crump. Terry as the Quality Manager is the central player in quality management and is currently working on the Quality Policy for certification under AS9100 Quality System. He is actually putting together the quality framework for Lola Composites. At the time of the interview, certification was due during the 3rd week of September 2006. His view of the company's drive on continuous improvement of quality actually confirmed some of the views expressed in the questionnaire. In a nutshell, his view is that quality at Lola is in the intensive care unit and will need proper resuscitation. However there are areas that he indicated that there are positive changes taking shaping. His views will be summarised in the following discussion.

4.4.1 Quality Issues:-

The interview with Terry Crump went beyond the structure of the questionnaire as each issue of the questionnaire was discussed in detail. Terry conceded that there is completely a lack of understanding of quality and its related issues. Although there is talk of tools and techniques to improve on quality e.g. there is no root cause failure analysis carried out on items before they are scrapped. He then gave the example of Lola Cars where RCFA is done on almost all scrapped components. Lola composites have now started to have regular quality meetings that also give feedback to the workers.

4.4.2 Cultural Issues

Cultural change at Lola must start with management, according to the Quality Manager. This is a strong message because even the quality gurus emphasise that change need to start at the top. Quality attitudes among both management and workers have not changed although there are positive steps that are starting to show at the present moment. Although management is pushing for that change now, the strategy they use will most likely determine whether positive results are achieved. The past period has seen quality improvement changes being imposed or dictated to people instead of having a buy-in, which according to Terry will encourage workers' participation and involvement. At the moment a blame-culture dominates, there is no ownership of both problems and solutions.

4.4.3 Human Issues

Generally the Lola Group does not recognise its people for quality initiatives and this has tended to have a negative impact on improvements. The organisation does not also discipline the workers for producing bad quality work. Another different source, a middle manager, commented that *'if someone is fully aware that nothing will happen for producing sub-standard work, then why should he bother.'* Its not only punitive methods that will change this kind of behaviour, there are a number of alternatives available, and training is one of them. Training has not been focussed on as a means of developing human resources but it must be noted that there is a positive trend at the moment to ensure continuous training of people. Individual effort and not teamwork is the current practice although the belief is that the company encourages teamwork.

4.4.4 Cost Issues

Poor quality is never discussed in terms of costs. There is need to distinguish between perception and reality when it comes to quality and pricing policy. The reality is that sourcing decisions are generally based on price and not quality although perceptions indicate the reverse.

4.4.5 Suppliers

There was an expression of doubt but the Quality Manager acknowledged that Lola is now placing emphasis on the quality being received from the suppliers. A supplier portal is now being developed and the company is starting to insist that suppliers must manufacture to specific standards e.g. ISO or BS. It is Lola's responsibility to specify its requirements and expectation from its customers.

4.4.6 Customers

Most customers do not give any feedback on the level of quality they get from Lola and ironically the company has not invested into establishing the levels of customer satisfaction. It is unfortunate according to Terry that some customers do not even understand the quality the want either and hence they will insist on having the work done as per drawing. For this reason, Lola must take a proactive approach and have the process engineers to fully understand the customer's expectation before proceeding with manufacturing.

4.5 The Lamination Process

It is very important and critical to ensure that the lay-up process is managed and carried out in a way that will maintain the structural integrity of the component or part. The quality control and inspection must focus on bonding preparation to make certain it is right and the curing process meet the required standard. It must be noted that even with the use of NDI, incorrectly processed laminate layers, if they have bonded, cannot be detected.

Designed bonding strength can only be achieved through control of process parameters such as temperature, pressure, curing time, humidity, surface roughness, chemical conditions, adhesive type and other environmental effects. Consequently, process control must be done for every step of the lamination process i.e. before and during the bonding process. Possible process flaws that will have an adverse effect on bond strength and quality include contamination, improper surface preparation, inclusions and incorrect processing especially on the direction of laminate layers. Contamination presents a unique problem in that it is the only flaw that cannot be detected by current quality assurance methods. This therefore puts a lot of pressure on clean room maintenance and material preparation.

4.5.1 Case Study 1: Effects of faulty Tooling on Quality

The purpose of this case study is to highlight some of the avoidable product quality problems. The component will just be referred to as automobile door. Its exact name or part numbers will not be disclosed due to trade secrecy between Lola and its customer.

The facts of the case are as follows:

The automobile door was moulded at Lola, using tooling supplied by the customer. Lola uses tooling it either makes itself or that provided by the customer. The tooling was inspected on receipt from the customer and confirmed to be not conforming due to excessive damage. The tooling had earlier been repaired but the repair putt was peeling off hence not fit for use. The customer was informed but insisted that the work go ahead using the damaged tooling, see Figure 10 below;

Figure 10: Damaged Mould Section

The Result:

- when the part was ready or had cured it was very difficult to remove
- the part was damaged due to the mould, see figure 10
- It was un-presentable and needed reworking.

Figure 11: Damage from Mould

The overall effect of manufacturing using non-conforming tooling was a damaged component which in turn:-

- created additional work from the resulting rework,
- create a bad image for the company especially to the third parties who may not have the privilege of getting to the full details of the matter and
- de-motivates and demoralises workers when they have to proceed with manufacturing a defective component because management have conceded to pressure form a customer to use faulty tooling.

The Lesson:-

The case illustrates that output is always influenced by the input. The results of the process are always related to the inputs. It is a clear case of the company's attitude towards quality and continuous improvement. The system was overridden and it is a clear instance of violating the same rules that should protect the company's quality values. The company has not defined its standards to its customers. Even if the customer may bear the cost of the rework but the damage that bad work may have on the company's image is irreparable.

If Lola wants to make positive steps in curbing use of faulty tooling from customers, it must set and comply with stringent requirements on tooling both provided in-house or from customers. Customers are an essential part of the business.

4.5.2 Case Study 2: An evaluation of the lay-up procedures

This case study involved the moulding of a fuel tank for a helicopter. The fuel tank falls within the group of aerospace components classified as Class 1 because it is a structural part, often moulded in the clean room. The clean room is prescribed because the material used is sensitive to environmental effects such as temperature, humidity, contamination, etc.

The issues raised from this exercise include:

- material direction,
- protective clothing
- continuous update of drawings
- inspection method
- material allowance

Material direction: It has a significant impact on the structural integrity of the component. Even though the laminator I worked with was able to identify the direction, this presents an opportunity for error because the diamond shape of the material is not easily identifiable especially if one is not very experienced or has sight difficulties.

Identifying direction of material must be made an easy and obvious task. Two suggestions will be made. The one that can be implemented immediately is providing magnifying glass and the resulting clear and big image is easily identifiable. The second option which is a long-term one will also includes material suppliers. Lola needs to insist to its suppliers that they supply all materials showing directions and angles. This in itself is a mistake-proofing device or measure.

4.5.3 Unstructured Interviews

The following are comments captured from unstructured interviews with the workers during the week long study tour. The comments from the workers reflected their general perceptions of the organisation and how they feel about the quality issues. It must be noted that the following are quotations, which if management take seriously may use as a starting point to address the culture.

'*We have not got time to do it properly but there is always time to do it again.'*:- This comment came from a middle manager when he was explaining that there is always pressure to get products out even if the available time and resources do not allows it to happen that way. According to the same manager, there is need to pay attention to quality at all.

'All the jobs are wanted yesterday and even some of the jobs that we will have planned ahead of time end up being very urgent jobs when they run behind

schedule. There are jobs that are pushed ahead without being planned. So when things are done in a hurry they may go wrong.'- This was from a team leader explaining management waivers on certain jobs.

'*Culture change, here? That is a big issue.*' A senior manager explaining how difficult it may be if Lola was to embark on changing the organisation's culture.

These comments speak volume of some of the things that Lola may need to address. In themselves, the comments show that the workers are conscious of what is supposed to be done and that possible could be the company's starting point.

4.6 Skill Matrix

Lola has formulated a skills matrix for the lamination section based on 22 main process co-competencies, Appendix 2***.*** It must be noted that for the purpose of this discussion, the following items although listed in the skills matrix given in Appendix 2, they will not be considered and these are moulding, fitting and pattern departments, 5-axis and clean-room procedure. The first column refers to the laminators and the percentages refer to the number of co-competencies a laminator has across the full range.

The skills matrix was established specifically to make an assessment of the lamination section's capability to carryout much of the tasks using the company's own human resources. It also evaluates the skills level of each and every worker in the department and using the same information it is possible to identify training needs. In terms of skills level, the table above, Table 6, 87.5% of the laminators are capable of doing at least 72% of different tasks with no need for independent inspection, which shows quite a high level of skilled workers.
There is only one or 6% designated in-process inspector, yet a total of 6 or 37.5% of the laminators are capable of performing as inspectors. The principle on its own is self-defeating. This is a visual aid displayed in the department's

general notice board and gives an impression that employees within this group can work with no one else to validate their work, yet there are defective components still being produced.

The other short-coming of the system is that it is failing to exploit the skills and fully utilise its human resources by allowing them to do what they are capable of. The ratio of in-process inspector to laminator at the moment is 1:15 yet this could be reduced significantly by allowing some of the workers designated to do the work.

4.7 Chapter Summary

This chapter has discussed the results of the research process that has included information gathering, responses to the questionnaire and interview with the Quality Manager, case studies from the lamination process as well as responses to the unstructured interviews.

Based on the information available there has been no significant improvement in the performance of the items that are not right first time even as well as the post delivery non-conformances. Major concerns are raised with the PCARs which are supposed to work as improvement initiatives. The PCARs must have maximum periods they can be allowed to remain open if real changes are to be realised. Improvements come from the manner in which data is analysed especially when RCFA is carried out and the results of the analysis fed back to the process.

The questionnaire results give a summary of the attitudes and views held by Lola employees on quality. The position of the Quality Manager confirms some of issues also revealed in the questionnaire which thus calls for change in approach to the way things are generally done. With the adoption of the quality policy a positive change in these attitudes is expected.

The case studies have also highlighted very important areas that present opportunities for improvement. Some of the problems are not actually of Lola's own making but still demand it to exercise prudent decisions. The case studies have also shown errors that are avoidable.

5. Conclusion and Discussion

5.1 Introduction

This chapter is built around the areas focused upon by the literature review, results from the data that was collected, the quality attitudes evaluation and the observation of the lamination process. The first section of this chapter will pay attention to issues raised as the objectives and will demonstrate the way in which these have been achieved. Basing on the findings of section two, recommendations will then be made to Lola on how best in-process inspection can be organised.

5.2 Discussion

5.2.1 Analysis of the investigation of the current lamination process

To make a detailed analysis of the current lamination process the evaluation was done starting with the lay-up books, the kit cutting process and then through the lamination shop. The other factor also analysed in detail is the human factor since this is a predominantly manual process.

To a large extent the success of the lamination process depends on the quality of information in the lay-up book, with regard to its clarity, completeness and currency. The method of kit cutting at the moment is not providing profiles and shapes that easily assist laminators to readily identify positions each unit must take. Kit cutting must provide leads and in this way laminators can articulate the process with ease. If the right profile is not made then there is reliance on the laminator’s common sense.

Tooling design especially on moulds, does not pay attention to the process after curing, i.e. mould release. Moulds need to be designed such that it is easy for the laminators to free the part once cured rather than use of brute force that may result in damaging the component. Tooling that is deemed ready for use must be having the necessary fasteners and this must be part of tooling inspection.

It is common practice to use tooling that is non-conforming especially if customers do not want to bear the cost either of new tooling or having the tooling repaired. When management make such waivers then the purpose of the QMS is defeated. Waivers compromise product quality and are impediments to the quality goal.

Lamination flaws can be minimised if the process is carried out in a clean environment. A designated clean environment and de-bulking is necessary as the current situation exposes all operations that are not done in the clean-room to contamination. Such changes may appear cosmetic, but since they are the ones workers often quote as a show of management unwillingness to provide a place for everything they create a huge impact in the direction of change.
Adhering to procedures is a big issue. Clean-room procedures for instance must apply to everyone, managers included.

5.2.2 Developing an in-process inspection based on employee involvement

The development of the in-process inspection must be done having in mind that the lamination is a very manual process that depends largely on the human element. The material sensitivity to environmental effects and conditions must be taken into account. The effectiveness of in-process inspection is also dependent on the workers i.e. the laminators because they actually do the work. Involvement of workers in this instance must include enabling users to participate in creating rules and standards and inspection must be reoriented towards observations of facts and problem solving. When inspection monitors individuals and instils blame then employees do not participate.

Rules and standards are normally defined at the design stage and this is the point at which there is need to tap from their experiences. A possible area for improvement from the present scenario is the F.M.E.A on the causes, it is simply put as '*Operator error*' Possible operator errors are not defined and listed most likely because even the designer is not aware of them. It is therefore important to get the operator to be involved in brain-storming and this can bring out both cause and possible ways of eliminating the problem at source.

Assist workers to do their work better and with ease. In most case people fail to do the work in the best possible way because they fail to visualise what they are expected to do. Make visual aids a part of the lay-up books. Along side the lamination drawing put the pictures that show the actual part when it is completed. Provide a reminder of the possible operator errors discussed above, show them on the working diagrams.

Make information readily available and accessible. Provide in their workshop computer terminals or information kiosks where they can surf through to get various stages of development of a component. Remember to allow them to access the internet and in that way the tool becomes theirs and hence users friendly.

Allow the workers to understand the customer and let the suppliers understand them too. Management normally wants to provide an interface between the workers and two key business partners. From the survey only 17% agree that Lola's quality standards meet customer expectations. Building on this acknowledgement of unsatisfactory performance, let the workers understand customers' concerns. When there is a quality problem, get the employees to the customer's site so that they see the problem for themselves. Only 32% agree that the suppliers meet Lola's quality expectations. It is equally important to get the same accountability from suppliers.

Recognise workers for quality work, any input to continuous improvement and for being part of the business. Employees need a sense of belonging. Remembering their birthdays, sending someone a *"get well soon"* message, little as they may appear, they count to motivation.

5.2.3 Human factors that affect quality in the lamination process

The study of the human factors has been much more complex because there are a number of issues that influence actions, attitude and behaviour. An evaluation of these attitudes and behaviours has been based on the responses of the questionnaire, the interview with the Quality Manager and the unstructured interviews with a number of workers, all of which were conducted during my study visit. The general expectations are to have a high performance in both physical and mental activities.

There is an inherent lack of professional etiquette among some of the workers especially when they commit wilful errors with the full knowledge that such actions will affect product quality. A case in point is possible contamination resulting from failure to wear protective gloves which are readily available.

Human behaviour will always need some energiser to stimulate it. Results from the survey indicate that Lola fall below the expectations of its workforce on rewards and recognition when it comes to issues relating to quality. It will be to the business' advantage if management will take steps to address the concerns that workers appear to have in this regard.

There is a general need to have a shared purpose. Employees are not in synchronous with management especially regarding the loading of work. What has been gathered from the discussions is management's focus in ensuring that it captures most of the customers by delivering what they want and when they want it. Management decisions need to be explained to the workers concerned, of any rescheduling of work especially if a job will be temporarily suspended in progress to push an order ahead of the queue. If employees understand the rationale of a decision, certainly they will support it.

5.2.4 Analysis of inspection methods and techniques

The fundamental principle and thinking around the current method of inspection is good. The inspection method, as it is done at the moment, is exhibiting both strengths and flaws. There are other problems inherent in the method of inspection by virtue of there being no tried and tested cost effective equipment aided techniques.

The system of self-checks coupled with independent in-process inspection is the one in force at Lola. Self-checks present a great opportunity for reducing defects because they give real-time feedback since the worker corrects his or her own errors before they become defects. What the workers need to guard against is bias and omissions.

The role of the independent in-process inspector has been compromised and his effectiveness reduced. The in-process inspector is still performing all his duties as a laminator yet he needs to check the work of the other laminators. The in-process inspector is not checking processes continuously but carrying out random checks only twice per day. This is ultimately working as a sampling method. The main disadvantage here is that defect-producing processes proceed unchecked in between the checks. There is argument that there are other senior laminators who check successive steps but these are people already tied up with their own business of the day. Even if they conduct the checks, they do not have time with the laminators and may not take them through the critical steps.

Inspection method is visual which makes it sensitive to the human element. Industrial standards have already shown that visual inspection account for between 80% and 90% of inspections done on composites structures. Visually checking composite structures is an extremely difficult process. The effectiveness of visually scanning parts is influenced by the training and experience an inspector has. This goes beyond basic laminator training but requires to be focusing on what to look for when carrying out the inspection.

Inspectors have their own bias and this is called the inspector's criterion. Knowledge from previous work will often influence their decisions today. As a result of this bias, the use of a single inspector in-process inspector will not be recommended. In-process inspection need to be conducted by a team so that a single job is inspected by more than one inspector at various stages and this can possibly give a balanced opinion.

The scope of in-process inspection needs to be broadened to cover processes other than the actual lamination. In-process inspection must not be based on the assumption that all defects occur during lamination. In-process inspectors require to audit the Kits, lay-up books, tooling and the lamination process itself.

Participants in in-process inspection gain on-the-job knowledge while carrying out their work in which case they must understand the cause and effect relationship. To broaden this knowledge they need active involvement in R.C.F.A and F.M.E.A when they brainstorm in teams. The focus is to increase awareness of possible causes, reduce bias and make inspection more objective.

Continuous evaluation of the inspectors, even by outsiders, will assist improve their skills. This need not be taken as performance appraisal since composite manufacturing is a fast growing field.

5.2.5 Continuous Improvement Strategy

Quality is a very important element in the market place and brings about competitive advantage. It takes form on the factory floor thus the focus of this continuous improvement strategy will be the shop floor. Improvement that is sustainable and continuous need to start from within the organisation and not instigated by outside forces e.g. when a major customer may insist that you must be ISO certified if they are to continue to do business with you. Standards certification is good especially if it is implemented amid on environment of continuous improvement.

Positive change comes when the focus is on changing the way we do our things, thinking and the interactions of various elements of the organisation.

This strategy will focus on the inter-relationship of the organisation, the process which makes products, and the individual who manages the process. Continuous improvement is a journey whose destination is difficult to reach when not done well. Using the results of the questionnaire and interviews as reflecting perceptions and opinions about Lola, the attention must be on the organisation.

The organisation:-the culture of the company, i.e. the values and beliefs must adopt a customer focus. We need to know with certainty what our customer wants, then ensure our processes are performing to surpass that level. Managers will need to be trained for quality, open their eyes for new thinking and create new intentions.

Successful training of top management gives then certain obligations

- creating a highly motivated workforce; by recognising contribution.
- training and encouraging individuals to participate in problem solving teams
- train and encourage all the employees in decision making. Respect those decisions and allow them to be tried. This is a great test to management's belief in culture change because most management structures do not want to relinquish some of its authority
- let employees speak openly about the organisation. Provide a frame-work for capturing those concerns

- expect resistance to the change process. Understand the concerns and manage them
- develop mutual trust

The Process: - The main objective of any change process is to do the right things first time and always. The processes are used for the purpose of creating value and product for the customers. Processes often involve cross-functional interaction.

For Lola cross-functional teams are used during the design and the manufacturing stages, so that failure modes can be identified and corrected at source. The composition of the cross-functional team is critical. It must represent function and not an office. The importance of this is to ensure that those involved with the process contribute directly and effectively during critical stages.

The individual: - It is worth mentioning that Lola does not believe in punishment and reprimands as discipline as evidenced by the survey. Therefore there should be means of getting people to produce high standards of work.

- The standard must be defined to the worker, in clear and easily understood language.
- Provide resources and support so that workers can do their work better.
- Lola has the skills matrix and hence every job thus coming must be matched against the skills matrix. Any special needs, with respect to the job, that the worker may need must be provided or met.
- Train must be a major priority. Training for composite manufacture need to cover not only the lamination activities but also material properties and inspection techniques.
- Teach and encourage the workforce to embrace teamwork, encourage individual participation.

- When workers make decisions in a team, normally it is based on a strong base of knowledge and experience. A very important element of such a decision is that they own it and they will do whatever it takes to make it work.
- Train the workers in using problem solving techniques. Demonstrate to them how the techniques help the process improve.
- Recognise and reward improvement initiatives.

5.2.6 Costing of Improvements

The findings of this research have not been costed. Most of the areas that were identified as being responsible for quality problems can actually be solved using internal resources. The problems have not been identified as due to deficiencies in the processes but in the way that we do our business. The only area that may need monetary investment is perhaps training but that should be insignificant. When we focus on improving inspection, it is not advisable at this stage to invest in any equipment for use during the lamination stage because evidence shows that it is still an area of on-going research.

5.3 Conclusions

In conclusion, from the research carried out at Lola, there are areas that are geared towards continuous improvement of quality and others that require to be addressed so that the quality goals are met.

The major highlight that shows the company’s commitment to quality and continuous improvement has been the Group Managing Director’s declaration of intent signed on 27 June 2006 i.e. the quality policy. That is what is often elusive in most companies, top management commitment. Now that it is in place, let it be used to steer the whole organisation to the quality goal

Lola has a good mix in terms of skills matrix. The study visits coincided with NVQ assessments which the company supports. The workers demonstrated great enthusiasm to this training, but Lola need to conduct targeted training e.g.

on inspection criteria, use of materials. Visual inspection is the commonly and widely used method of inspection, commanding 80% to 90%.

It is the method applied to both self-checks and in-process inspection. From literature and industrial inquiry, it is apparent that at the moment there are no cost effective instrument aided techniques reliable enough to replace visual inspection. As a consequence, it is prudent to conduct training that makes laminators proficient in inspect techniques.

Communication is a vital link between various units or elements of the business. Without it even good business initiatives may not get the necessary support. For as long as people do not feel to be part of a decision they may not feel obliged to support it.

Involvement of workers in the various stages of the product's life cycle is essential, stimulate interest. Let them take part in DFMEA and PFMEA, and when problems occur during manufacture they will be the first to give feedback. It is important for everyone to understand design limitations so that they work together to overcome them. Instil in workers high levels of discipline, accountability and responsibility. They need to understand procedures not just as rules but as part of the process itself.

Quality can only be adopted as the business ethos if it is approached with a shared purpose among management, workers, customers and suppliers. Each level or category contributes to quality in unique in a way.

Management will define the direction and provide resources, customers are needed to clearly outline their expectation, and suppliers provide materials that are, according to Lola's expectations, conforming to requirements and the workers make the product. If any of these fail to meet minimum standards then quality is compromised.

This research study has not focused on financial investment as being the main ingredient in the continuous improvement process. There is no desire to invest in technology aided inspection techniques especially for the lamination process because aerospace companies like Airbus are stuck with visual inspection. The market is still to have such products made available.

Another approach that could also have been taken would have been to bench-mark Lola's quality performance against its competitors. The researcher failed to pursue that path on the pretext that sometimes benchmarking ends up being like transferring problems from elsewhere to Lola. The other problem encountered has been that competitors in this business keep high levels of secrecy on their products thus generally companies are unwilling to cooperate once they know you are working with a competitor.

In closing it must be borne in mind that quality will always be looked at differently. It is a journey whose end never comes but has a very significant role to play in business competitiveness.

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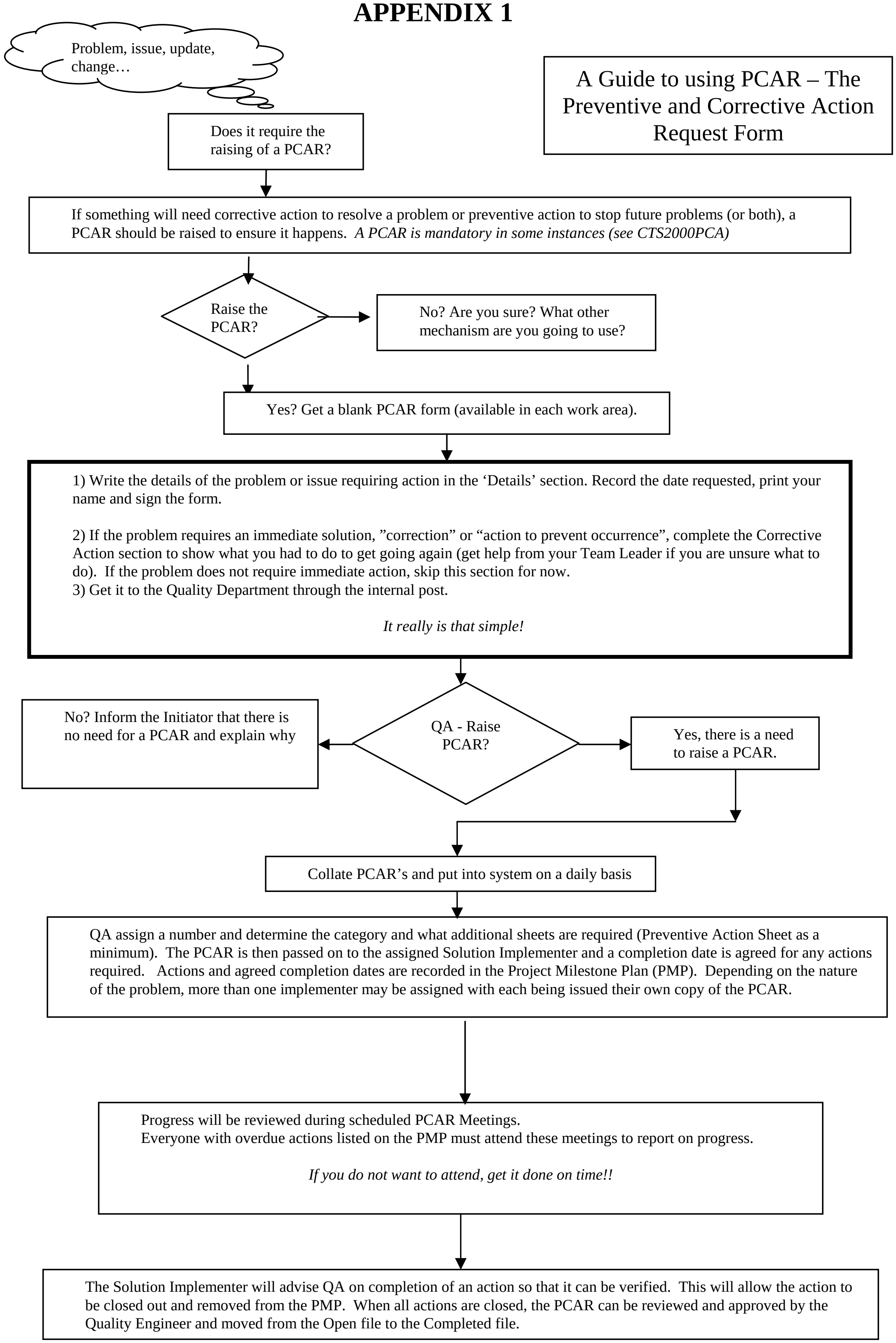
APPENDIX 1



A Guide to using PCAR – The Preventive and Corrective Action Request Form
Problem, issue, update, change…
Does it require the raising of a PCAR?
If something will need corrective action to resolve a problem or preventive action to stop future problems (or both), a PCAR should be raised to ensure it happens. *A PCAR is mandatory in some instances (see CTS2000PCA)*
Raise the PCAR?
No? Are you sure? What other mechanism are you going to use?
Yes? Get a blank PCAR form (available in each work area).
1) Write the details of the problem or issue requiring action in the 'Details' section. Record the date requested, print your name and sign the form.
2) If the problem requires an immediate solution, "correction" or "action to prevent occurrence", complete the Corrective Action section to show what you had to do to get going again (get help from your Team Leader if you are unsure what to do). If the problem does not require immediate action, skip this section for now.
3) Get it to the Quality Department through the internal post.
It really is that simple!
QA - Raise PCAR?
No? Inform the Initiator that there is no need for a PCAR and explain why
Yes, there is a need to raise a PCAR.
Collate PCAR's and put into system on a daily basis
QA assign a number and determine the category and what additional sheets are required (Preventive Action Sheet as a minimum). The PCAR is then passed on to the assigned Solution Implementer and a completion date is agreed for any actions required. Actions and agreed completion dates are recorded in the Project Milestone Plan (PMP). Depending on the nature of the problem, more than one implementer may be assigned with each being issued their own copy of the PCAR.
Progress will be reviewed during scheduled PCAR Meetings.
Everyone with overdue actions listed on the PMP must attend these meetings to report on progress.
If you do not want to attend, get it done on time!!
The Solution Implementer will advise QA on completion of an action so that it can be verified. This will allow the action to be closed out and removed from the PMP. When all actions are closed, the PCAR can be reviewed and approved by the Quality Engineer and moved from the Open file to the Completed file.

Appendix 2

Skills Matrix For Lola Composite Lamination Shop

		One Piece Chassis	Roll Hoops	Split Chassis	Bulkheads	Nose Cones	1 Piece wings & flaps	Mainplanes	Flaps	Sidepods	Tails	Underbody	Wing Endplates	Brake Ducts	Bond Cowling	Bond Parts	Aerospace	Meggitt Fuselage	Meggitt Wings	Airbus wind tunnel blade	Reading Drawings	Phenolic Laminating	Mould Department	Clean Room Procedure	In process inspection
1	Mark Furness	U	O	O	O	U	O	O	O	O	O	O	O	O	L	U	U	L	L	U	U	O		O	O
2	Toby Satterly	L	O	L	O	U	O	O	O	O	O	O	O	O	U	O	U	U	L	U	U	O		O	L
3	Stuart Avory	L	O	L	O	O	O	O	O	O	O	O	O	O	L	U	U	L	L	U	U	O		O	I
4	Mick Hinds	L	U	L	O	O	O	O	O	O	U	O	O	O	L	U	U	L	L	U	U	O		O	I
5	Andy White	U	O	O	O	O	O	O	O	O	O	U	O	O	L	U	U	U	L	U	U	O		O	I
6	Brian Kitchin	O	O	O	O	O	O	O	O	O	O	O	O	O	L	U	U	L	L	U	U	O		O	I
7	Kevin Thorne	O	O	O	O	O	O	O	O	O	O	O	O	O	L	U	U	U	O	O	U	O		O	O
8	Tony Mulgrew	O	O	O	O	O	O	O	O	O	O	O	O	O	L	U	U	U	O	U	U	O		O	I
9	Jeff Maskell	L	O	L	O	O	O	O	O	O	O	O	O	O	L	U	U	O	U	L	U	O	U	O	O
10	A Ambrosio	U	L	L	O	O	O	O	O	O	O	U	O	O	L	L	L	U	O	I	O	O	L	O	O
11	Mark Ives	L	O	U	O	O	O	O	O	O	O	O	O	O	O	O	L	L	L	U	U	O	U	O	O
12	Marin Parr	O	O	O	O	O	O	O	O	O	O	O	O	O	U	O	O	O	U	U	U	O		O	L
13	Nicola Smith	L	U	L	O	U	O	O	O	O	U	O	O	O	U	O	U	L	L	L	L	U		O	I
14	Ben Fihelebon	O	O	O	O	O	O	O	O	O	O	O	O	O	U	O	U	O	U	U	U	O		O	O
15	Bruce Myhill	I	I	I	L	I	U	O	O	O	L	O	O	O	I	I	I	I	I	I	U	I	I	O	I
16	Monika Stolarsk	I	I	I	L	I	U	O	O	O	O	O	O	O	I	I	I	I	I	I	L	I	I	O	I

KEY

- I Trainee must be supervised
- L Can do the job, needs checking and coaching
- U Can do the job at full speed and does not need inspecton
- O Can do the job at full speed and does not need inspecton-can also train
- (red) Designated dual-skill for prepreg Mould laminating
- (cyan) Designated dual-skill for prepreg Mould and wet laminating
- (yellow) Designated dual-skill for Fitting
- (purple) Designated dual-skill for Kit Cutting
- (orange) Designated in process inspector

Reviewed by Team Leader-Mark Furness

Authorised by Manager-Chris Palmer

LAST UPDATED- 09/06/2006

Appendix 3

Questionnaire on Lola Quality Attitudes

1. At Lola everyone fully understands what quality is?

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

2. There has been a significant change in attitude towards quality exhibited by management over the last five years.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

3. There has been a significant change in attitude towards quality exhibited by workers over the last five years.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

4. Poor quality is a huge cost to our company.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

5. There are initiatives that we at Lola are taking to ensure our products conform to specifications.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

6. Everyone is fully aware of the techniques and tools our company has in place to improve on quality

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

7. Every little bit counts when it comes to quality. This is also the way we think at Lola.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

8. Rewards or praises are given in recognition of good quality initiatives.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

9. Punishment and reprimand can be instituted for producing poor quality results.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

10. Employees are aware of the Quality Policy/Systems in force at Lola.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

11. Lola pays a lot of attention to the quality we receive from our supplies.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

12. Our suppliers are fully aware of our quality requirements.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

13. Quality and not price is the crucial factor in our sourcing decisions.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

14. Price and not quality is the crucial factor in our sourcing decisions.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

15. We levy penalties to our suppliers, for poor quality.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

16. We insist on suppliers that manufacture to specific internationally recognised standards e.g. BS/ISO.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

17. Just as we make concessions with our customers, we also do the same with our suppliers.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

18. Training on quality and continuous improvement is an on-going activity in our company.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

19. Lola encourages teamwork than individual effort.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

20. Resources for any job are always made available before the work starts.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

21. Our customers are satisfied with the level of our quality.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

22. We fully understand our customers' expectations with regard to quality.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

23. Concessions are a bad business practice when it comes to quality.

Strongly Agree	Agree	Hmmmmm	Disagree	Strongly Disagree

Thank you for participating in this exercise. We value your contribution and your time. Please show your employment category in the boxes below.

Senior Management ☐

Middle Management ☐

Work Force ☐

Questionnaire Summated Scores

Questionnaire Summated Scores for Respondents A to P for Questions 1 -

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	3	4	3	3	4	4	2	2	4	4	2	1	3	4	3
2	2	2	2	4	2	4	2	3	4	2	4	2	2	2	2
3	3	3	4	3	2	3	3	2	3	3	2	2	3	3	4
4	1	2	1	1	2	1	2	4	1	1	1	1	1	2	1
5	4	5	4	4	4	5	3	5	4	4	4	2	4	5	4
6	1	4	2	3	2	4	2	3	4	3	2	2	1	4	2
7	2	2	4	3	4	1	3	3	4	3	3	2	2	2	4
8	1	3	2	2	2	1	1	2	5	2	2	1	1	3	2
9	4	4	4	4	4	2	4	4	3	4	3	3	4	4	4
10	3	4	4	3	2	5	2	2	4	4	3	2	3	4	4
11	2	3	1	4	2	2	2	4	3	3	3	3	2	3	1
12	2	4	2	3	2	2	3	4	4	3	3	2	2	4	2
13	1	1	2	2	2	1	3	1	3	3	5	2	1	1	2
14	1	2	1	2	2	1	2	1	3	3	5	2	2	1	2
15	1	3	1	4	2	1	3	2	3	4	3	2	3	1	4
16	3	4	1	4	2	4	2	3	4	4	4	2	4	3	4
17	1	4	2	4	4	4	3	4	2	3	4	2	4	1	4
18	1	3	2	3	2	2	3	1	3	3	4	2	3	1	3
19	2	3	2	2	3	3	3	1	3	4	2	2	3	2	2
20	1	1	1	2	5	1	1	2	2	2	2	1	1	1	2
21	2	2	2	3	4	2	3	4	3	3	3	3	2	2	3
22	2	2	2	4	3	2	3	2	4	3	2	2	2	2	4
23	1	1	1	3	4	2	3	2	2	1	4	2	1	1	3
Summated Scores	44	66	50	70	65	57	58	61	75	69	70	45	54	56	66

Respondents	Sum
I	**75**
D	**70**
K	**70**
J	**69**
B	**66**
O	**66**
E	**65**
H	**61**
G	**58**
F	**57**
N	**56**
M	**54**
C	**50**
L	**45**
A	**44**

n2	115
n1	23
mid-range	69

n1 is the minimum possible score

n2 is the maximum possible score

Summated Scores for Responses to Quality Related Issues

1	**3**	**4**	**3**	**3**	**4**	**4**	**2**	**2**	**4**	**4**	**2**	**1**	**3**	**4**	**3**
5	**4**	**5**	**4**	**4**	**4**	**5**	**3**	**5**	**4**	**4**	**4**	**2**	**4**	**5**	**4**
6	**1**	**4**	**2**	**3**	**2**	**4**	**2**	**3**	**4**	**3**	**2**	**2**	**1**	**4**	**2**
7	**2**	**2**	**4**	**3**	**4**	**1**	**3**	**3**	**4**	**3**	**3**	**2**	**2**	**2**	**4**
10	**3**	**4**	**4**	**3**	**2**	**5**	**2**	**2**	**4**	**4**	**3**	**2**	**3**	**4**	**4**
11	**2**	**3**	**1**	**4**	**2**	**2**	**2**	**4**	**3**	**3**	**3**	**3**	**2**	**3**	**1**
12	**2**	**4**	**2**	**3**	**2**	**2**	**3**	**4**	**4**	**3**	**3**	**2**	**2**	**4**	**2**
Summated Scores	**17**	**26**	**20**	**23**	**20**	**23**	**17**	**23**	**27**	**24**	**20**	**14**	**17**	**26**	**20**

Respondents	Sum
G	27
D	26
L	26
F	24
J	23
O	23
H	23
K	20
B	20
N	20
A	20
I	17
E	17
C	17
M	14

n2	35
n1	7
mid-range	21

Summated Scores for Responses on Cultural Issues

2	**2**	**2**	**2**	**4**	**2**	**4**	**2**	**3**	**4**	**2**	**4**	**2**	**2**	**2**	**2**
3	**3**	**3**	**4**	**3**	**2**	**3**	**3**	**2**	**3**	**3**	**2**	**2**	**3**	**3**	**4**
18	**1**	**3**	**2**	**3**	**2**	**2**	**3**	**1**	**3**	**3**	**4**	**2**	**3**	**1**	**3**
19	**2**	**3**	**2**	**2**	**3**	**3**	**3**	**1**	**3**	**4**	**2**	**2**	**3**	**2**	**2**
20	**1**	**1**	**1**	**2**	**5**	**1**	**1**	**2**	**2**	**2**	**2**	**1**	**1**	**1**	**2**
23	**1**	**1**	**1**	**3**	**4**	**2**	**3**	**2**	**2**	**1**	**4**	**2**	**1**	**1**	**3**
Summated Scores	**10**	**12**	**11**	**14**	**14**	**13**	**12**	**9**	**15**	**14**	**14**	**9**	**12**	**9**	**13**

Respondents	Sum
I	15
D	14
E	14
J	14
K	14
F	13
O	13
B	12
G	12
M	12
C	11
A	10
H	9
L	9
N	9

n2	30
n1	6
mid-range	18

Summated Scores for Responses to Cost Related Issues

4	**1**	**2**	**1**	**1**	**2**	**1**	**2**	**4**	**1**	**1**	**1**	**1**	**1**	**2**	**1**
13	**1**	**1**	**2**	**2**	**2**	**1**	**3**	**1**	**3**	**3**	**5**	**2**	**1**	**1**	**2**
14	**1**	**2**	**1**	**2**	**2**	**1**	**2**	**1**	**3**	**3**	**5**	**2**	**2**	**1**	**2**
Summated Scores	**3**	**5**	**4**	**5**	**6**	**3**	**7**	**6**	**7**	**7**	**11**	**5**	**4**	**4**	**5**

Respondents	Sum
K	11
G	7
I	7
J	7
E	6
H	6
B	5
D	5
L	5
O	5
C	4
M	4
N	4
A	3
F	3

n2	15
n1	3
mid-range	9

Summated Scores for Responses to Human Issues

8	**1**	**3**	**2**	**2**	**2**	**1**	**1**	**2**	**5**	**2**	**2**	**1**	**1**	**3**	**2**
9	**4**	**4**	**4**	**4**	**4**	**2**	**4**	**4**	**3**	**4**	**3**	**3**	**4**	**4**	**4**
Summated Scores	**5**	**7**	**6**	**6**	**6**	**3**	**5**	**6**	**8**	**6**	**5**	**4**	**5**	**7**	**6**

Respondents	Sum
I	8
B	7
N	7
C	6
D	6
E	6
H	6
J	6
O	6
A	5
G	5
K	5
M	5
L	4
F	3

n2	10
n1	2
mid-range	6

Summated Scores for Responses on Stakeholders Related Issues

15	**1**	**3**	**1**	**4**	**2**	**1**	**3**	**2**	**3**	**4**	**3**	**2**	**3**	**1**	**4**
16	**3**	**4**	**1**	**4**	**2**	**4**	**2**	**3**	**4**	**4**	**4**	**2**	**4**	**3**	**4**
17	**1**	**4**	**2**	**4**	**4**	**4**	**3**	**4**	**2**	**3**	**4**	**2**	**4**	**1**	**4**
21	**2**	**2**	**2**	**3**	**4**	**2**	**3**	**4**	**3**	**3**	**3**	**3**	**2**	**2**	**3**
22	**2**	**2**	**2**	**4**	**3**	**2**	**3**	**2**	**4**	**3**	**2**	**2**	**2**	**2**	**4**
Summated Scores	**9**	**15**	**8**	**19**	**15**	**13**	**14**	**15**	**16**	**17**	**16**	**11**	**15**	**9**	**19**

Respondents	Sum
D	19
O	19
J	17
I	16
K	16
B	15
E	15
H	15
M	15
G	14
F	13
L	11
A	9
N	9
C	8

n2	25
n1	5
mid-range	15

Appendix 4

Lola Composites Quality Policy Statement from the Group Managing Director, turn to next page.

Lola House
Glebe Road, St Peters Road
Huntingdon, Cambs , PE29 7DS

Quality Policy

It is the policy of Lola to provide high quality products and design services, which meet all of the customer's requirements, and also meet the requirements of applicable legislation and codes of practice including ISO9001/2000 and AS9100.

Quality is included as a key item in the Lola business plans and is thereby linked directly to the success of the business at the highest possible level. Management reviews the performance of the Quality Management System regularly against business objectives and sets revised objectives when necessary.

The key Lola objective is to ensure that all customers are completely satisfied with the products and services they have received from Lola and to establish a best in class position with our customers.

Management has implemented this comprehensive Quality Management System which describes in detail how work is to be done, how work is to be reviewed and measured, and how the Quality performance of Lola will be improved.

Compliance with the requirements of this Quality Management System is mandatory on all personnel.

Responsibility for overseeing the implementation of this Quality Management System is delegated to the Quality Manager who is a Senior Manager of the company and reports directly to the Managing Director. The Quality Manager has the authority to take any action necessary to ensure compliance with the standard and associated legislation and to liase with Customers and Legislative Authorities.

A Morris
Group Managing Director

27th June 2006

Appendix 5

Lola Composites Component Check Sheet, turn to next three (3) pages.

LOLA COMPOSITES	COMPONENT CHECK SHEET	Category A	Class 3

Sub Ass: 066-10802 **Desc:** 0640-01622--01 TAIL MOUNTING BEAM LW

Order : **Rev:** 1 **Rev Date:** 31-Mar-2006 **Lay Up Issue:** 1

Op No	Description	Comp By	Inspection Details	Insp By
10	Tooling Check. Ensure mould has been fully released in accordance with SOP-MOU-01 or SOP-MOU-02.		-	
20	1 ply of LCW (C32) @ 0/90 all over. OVERLAPS MUST BE NO LARGER THAN 10MM IN ANY AREA!		Check neatness of first layer. Check all overlaps are no larger than 10mm.	
30	1 ply of LCW (C32) @ +/-45 all over. OVERLAPS MUST BE NO LARGER THAN 10MM IN ANY AREA!		Check all overlaps are no larger than 10mm.	
40	Position SIX Tufnol Inserts (02-TU-S-12 - 4 off & 08-TU-S-16 - 2 off)		Check as per lay-up specification	
50	1 ply of LCW (C32) @ +/-45 to the flanges and inserts.		-	
60	2 plies of LCW (C32) @ +/-45 & 0/90 to the areas shown.		Check Ops.50 & 60 as per lay-up specification	
70	2 plies of SCW (C33) @ 0/90 to the edges shown.		Check as per lay-up specification	
80	Bag up for the autoclave with cloth all over, non-perforated release film all over and heavy breather. (LCUR No.77) In accordance with SOP-LAM-10		Check bagging	
90	1 ply of FM87 filmbond 150g (F33) all over.		Check the filmbond has not been overlaped in any areas.	
100	2 plies of LCW (C32) @ +/-45 & 0/90 to the areas shown.		-	
110	Position 1/2" Nomex Core (N14) to the area shown.		Check as per lay-up specification	
115	Position 1/8" Nomex Core (N1) to the area shown.		Check as per lay-up specification	
120	Strips of FM87 filmbond 150g (F33) to the edges of core.		Check the filmbond has not been overlaped in any areas.	
130	2 plies of LCW (C32) @ 0/90 & +/-45 to the areas shown.		Check as per lay-up specification	
150	1 ply of LCW (C32) @ 090 all over. OVERLAPS MUST BE NO LARGER THAN 10MM IN ANY AREA!		Check all overlaps are no larger than 10mm.	
160	Bag up for the autoclave with perforated release film all over and heavy breather. (LCUR No.76 - 30psi) In accordance with SOP-LAM-10		Check bagging	

Sub Ass: 066-10802	Desc: 0640-01622--01 TAIL MOUNTING BEAM LW			
Order :	Rev: 1	Rev Date: 31-Mar-2006	Lay Up Issue: 1	

Op No	Description	Comp By	Inspection Details	Insp By

Cracked Out By:		Leads:			Taps:			Sensor:			
Autoclave No:		Cure ID No:									

Sign to confirm all tooling is present and in acceptable condition - prior to storage: ___________

Sub Ass:	066-10802
Comp No:	
Lay Up Iss:	1

Sub Ass:	066-10802
Comp No:	
Lay Up Iss:	1

LOLA COMPOSITES	COMPONENT CHECK SHEET	Category	Class
		A	3

Sub Ass: 066-04418 **Desc:** 0540-01066--01 LH MOUNT FLANGE BALANCE P

Order : 513701 **Rev:** 1 **Rev Date:** 23-Nov-2004 **Lay Up Issue:** 1

Op No	Description	Comp By	Inspection Details	Insp By
10	Tooling Check. Flush off all dowel holes.	BF	-	
20	1 ply of HCW (C34) @ +/-45 all over.	BF	-	
30	1 ply of HCW (C34) @ 0/90 all over.	BF	-	
40	1 ply of HCW (C34) @ 0/90 all over.	BF	-	
50	1 ply of HCW (C34) @ +/-45 all over.	BF	-	
60	Position pressure plate. Bag up for the autoclave with non-perforated release film all over and heavy breather. (LCUR No.77 - 60psi)	BF	Check bagging	[signature]

Cracked Out By:	ALO	**Leads:**	2	**Taps:**	1	**Sensor:**	11
Autoclave No:	1	**Cure ID No:**	7091				

Sub Ass:	066-04418
Comp No:	513701
Lay Up Iss:	1

Appendix 5

Process Failure Mode and Effect Analysis Sheet

POTENTIAL

FAILURE MODE AND EFFECTS ANALYSIS

(PROCESS FMEA)

Print # ____________ Rev. 2

FMEA Number: Lola Composites 01

Item: Production Laminating

Process Responsibility: Lance Mayers

Prepared by: Ken Preston

Model Year(s)/Vehicle(s): ____________

Key Date: 16/05/2005

Date (Orig.): 16/05/2005

Core Team: L Mayers, M Furness

Date (Rev.): 08/072005

Process Function/ Require-ments	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Process Controls Prevention	Current Process Controls Detection	Detec	R.P.N.	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Sev	Occ	Det	R.P.N.
05 Mould tool preperation	Contamination and or excessive release applied	Poor appearance (Customer disatisfaction)	7		Poor houskeeping /poor handling	4	Standard Operating Procedures	Component check sheet	3	84							
	Insufficient release applied	Difficulty extracting	2		Operator error	3	Standard Operating Procedures	Component check sheet	6	36							
10 Receiving Kit	Incorrect Plies selected	Rework	2		Operator error	2	Standard Operating Procedures	Component check sheet	7	28							
10 Lay up Pre Preg into mould	Incorrect position	Potential Failure	2		Operator error	2	Component check sheet/ Lay up Book	Checklist	6	24							
	Porosity	Potential Failure	2		Operator error	3	Component check sheet/ Lay up Book	PreTrim Inspection Checklist	2	12							
	Bridging	Potential Failure	7		Operator error	4	Component check sheet/ Lay up Book	PreTrim Inspection Checklist	3	84	Lok at trends Identify causes Produce SOP for Lay-up on Pre-preg	Lance Mayers 1 August 2005					
	Witness Marks from mould	Potential Failure	3		Poor houskeeping /poor handling	4	Component check sheet/ Lay up Book	PreTrim Inspection Checklist	3	36							
	Resin Rich Corners	Rework	3		Operator error	4	Component check sheet/ Lay up Book	PreTrim Inspection Checklist	3	36							
	Plies missing	Total Failure	8		Operator error	2	Component check sheet	PreTrim Inspection Checklist	4	64							
10 Bagging	Bag Damage	Poor consolidation	7		Poor handling	4	Component check sheet	Checklist	3	84							
12 Vacuum test	Insufficient Vacuum	Poor consolidation	7		Leaking bag mould or hoses	4	Component check sheet, Vacuum Gauge	PreTrim Inspection Checklist / Autoclave temp/vac printout	3	84							
15 Autoclave cure	Insufficient cure	Poor consolidation	7		Gauge Indicators	4	Regular maintenance	Checklist	2	56							
20 Drill/Cracking out	Drilled incorrect	Difficulty extracting	8		Operator error	7	Standard Operating Procedures	PreTrim Inspection Checklist	2	112	Produce SOP Designate area Obtain tools	Ken Preston 1 July 2005					
	Delamination	Poor Crack out technique	6		Operator error	5	Standard Operating Procedures	PreTrim Inspection Checklist	3	90							

POTENTIAL
FAILURE MODE AND EFFECTS ANALYSIS
(PROCESS FMEA)

Print # ______ Rev. 2

FMEA Number: Lola Composites 01

Item: Production Laminating

Process Responsibility: Lance Mayers

Prepared by: Ken Preston

Model Year(s)/Vehicle(s): ______

Key Date: 16/05/2005

Date (Orig.): 16/05/2005

Core Team: L Mayers, M Furness

Date (Rev.): 08/072005

Process Function/ Require-ments	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Process Controls Prevention	Current Process Controls Detection	Detec	R.P.N.	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Sev	Occ	Det	R.P.N.
	Scratched	Difficulty extracting	6		Operator error	5	Standard Operating Procedures	PreTrim Inspection Checklist	3	90							
	Split Panel	Potential Failure	7		Operator error	5	Component check sheet	PreTrim Inspection Checklist	2	70							
	Mould damage	Difficulty extracting	6		Operator error	3	Standard Operating Procedures	PreTrim Inspection Checklist	3	54							

Appendix 6

Lola Composites Control Plan turn to next five (5) pages.

CONTROL PLAN

☐ Prototype ☐ Pre-Launch ☑ Production

Control Plan Number	Key Contact/Phone	Date (Orig.)	Date (Rev.)
Lola Composites Process	Ken Preston 01480 359517	13/05/2005	13/05/2005
Part Number/Latest Change Level: N/A	Core Team: L Mayers, M Furness	Customer Engineering Approval/Date (If Req'd.)	
Part Name/Description: Production Laminating	Supplier/Plant Approval/Date	Customer Quality Approval/Date (If Req'd.)	
Supplier/Plant / Supplier Code	Other Approval/Date (If Req'd.)	Other Approval/Date (If Req'd.)	

PART/ PROCESS NUMBER	PROCESS NAME/ OPERATION DESCRIPTION	MACHINE, DEVICE, JIG,TOOLS, FOR MFG.	CHARACTERISTICS			SPECIAL CHAR. CLASS	METHODS					REACTION PLAN
			NO.	PRODUCT	PROCESS		PRODUCT/PROCESS SPECIFICATION/ TOLERANCE	EVALUATION/ MEASUREMENT TECHNIQUE	SAMPLE SIZE	SAMPLE FREQ.	CONTROL METHOD	
OP 5	Mould tool preperation	Mould tool		Ensure that mould tool is available			part is available	Visual	100%	100%		Inform team leader and investigate
				Mould tool must be free from debris & contam			No debris and contamination is acceptable	Visual	100%	100%	Component check sheet/ Standard Operating Procedure	Clean tool to ensure compliance to requirement
				Correct amount of release agent			Continious even coat of Marbacote	Visual by operator	100%	100%		
				No excessive deterioration to mould				Visual	100%	100%	Standard Operation Procedure	Inform team leader if any deterioration
OP 10	Laminate to Customer approved Layup			Wrinkles /Creases			If wrinkles cannot be smoothed out reject	Visual	100%	100%	Component check sheet	Inform team leader and place on hold
	Bagging - Apply non perforated release cloth and heavy breather			Wrinkles /Creases			No excessive wrinkles or creases	Visual	100%	100%	S O P for Vac Bagging	Inform team leader and place on hold

CONTROL PLAN

☐ Prototype ☐ Pre-Launch ☑ Production

Control Plan Number Lola Composites Process		Key Contact/Phone Ken Preston 01480 359517	Date (Orig.) 13/05/2005	Date (Rev.) 13/05/2005
Part Number/Latest Change Level N/A		Core Team L Mayers, M Furness	Customer Engineering Approval/Date (If Req'd.)	
Part Name/Description Production Laminating		Supplier/Plant Approval/Date	Customer Quality Approval/Date (If Req'd.)	
Supplier/Plant	Supplier Code	Other Approval/Date (If Req'd.)	Other Approval/Date (If Req'd.)	

PART/ PROCESS NUMBER	PROCESS NAME/ OPERATION DESCRIPTION	MACHINE, DEVICE, JIG,TOOLS, FOR MFG.	CHARACTERISTICS			SPECIAL CHAR. CLASS	METHODS					REACTION PLAN
			NO.	PRODUCT	PROCESS		PRODUCT/PROCESS SPECIFICATION/ TOLERANCE	EVALUATION/ MEASUREMENT TECHNIQUE	SAMPLE SIZE	SAMPLE FREQ.	CONTROL METHOD	
OP12	Apply Vacuum Bag				Bag not damaged		No holes, splits, creases and imperfections	Visual	100%	100%	S O P for Vac Bagging	Replace with new bag
					Vacuum Test		No vacuum leak for 5 min minimium	Vacuum Gauge	100%	100%	S O P for Vac Bagging	Investigate leak and rectify
OP15	Autoclave Cure	Autoclave			LCUR as required		Autoclave temp and vacuum	Visual	100%	100%	Defined in Component check sheet	Inform team leader, inspect part and investigate
OP 20	Drill off Panel			Drilled correctly			Part must not move in mould	Visual	100%	100%	Examine at Pre Trim Inspection once removed from mould	Raise Defect Note and place in on hold rack
	Crack out Panel			Part not damaged			No damage allowed to part when removed from mould	Visual	100%	100%	Component Check Sheet	
	Identify Part				Part marking		Identify by unique comp No	Visual to Comp Check Sheet	100%	100%	Standard Operation	
OP 30	Pre-trim inspection			Porosity on Surface			No porosity acceptable	Visual and Surface roughness tester	100%	100%	Book item through pre trim inspection	

CONTROL PLAN

☐ Prototype ☐ Pre-Launch ☑ Production

Control Plan Number Lola Composites Process		Key Contact/Phone Ken Preston 01480 359517	Date (Orig.) 13/05/2005	Date (Rev.) 13/05/2005
Part Number/Latest Change Level N/A		Core Team L Mayers, M Furness	Customer Engineering Approval/Date (If Req'd.)	
Part Name/Description Production Laminating		Supplier/Plant Approval/Date	Customer Quality Approval/Date (If Req'd.)	
Supplier/Plant	Supplier Code	Other Approval/Date (If Req'd.)	Other Approval/Date (If Req'd.)	

PART/ PROCESS NUMBER	PROCESS NAME/ OPERATION DESCRIPTION	MACHINE, DEVICE, JIG,TOOLS, FOR MFG.	CHARACTERISTICS			SPECIAL CHAR. CLASS	METHODS					REACTION PLAN
			NO.	PRODUCT	PROCESS		PRODUCT/PROCESS SPECIFICATION/ TOLERANCE	EVALUATION/ MEASUREMENT TECHNIQUE	SAMPLE SIZE	SAMPLE FREQ.	CONTROL METHOD	
							Any surface imperfections	Visual and Surface roughness tester	100%	100%	Raise Defect Note and place in on hold rack	Carry out Quality Investigation
				Bridging on surface			No brigging acceptable	Visual	100%	100%	Book item through pre trim inspection	Trim shop to rectify
							Less than or equal to 5 mm	Visual and Ruler	100%	100%	Rework as per Standard Operation	
							Greater than 5 mm	Visual and Ruler	100%	100%	Raise Defect Note and place in on hold rack	Carry out Quality Investigation
				Resin Starvation			Not Acceptable	Visual	100%	100%	Book item through pre trim inspection	
							Flaw up to 20mm	Visual and Ruler	100%	100%	Rework as per Standard Operation	
							Greater than 20 mm	Visual and Ruler	100%	100%	Raise Defect Note and place in on hold rack	Carry out Quality Investigation
				Scratch to surface			If scratch cannot be felt with finger nail scratch is acceptable	Feel and Visual	100%	100%	Book item through pre trim inspection	

CONTROL PLAN

☐ Prototype ☐ Pre-Launch ☑ Production

Control Plan Number Lola Composites Process	Key Contact/Phone Ken Preston 01480 359517	Date (Orig.) 13/05/2005	Date (Rev.) 13/05/2005
Part Number/Latest Change Level N/A	Core Team L Mayers, M Furness	Customer Engineering Approval/Date (If Req'd.)	
Part Name/Description Production Laminating	Supplier/Plant Approval/Date	Customer Quality Approval/Date (If Req'd.)	
Supplier/Plant / Supplier Code	Other Approval/Date (If Req'd.)	Other Approval/Date (If Req'd.)	

PART/ PROCESS NUMBER	PROCESS NAME/ OPERATION DESCRIPTION	MACHINE, DEVICE, JIG,TOOLS, FOR MFG.	CHARACTERISTICS			SPECIAL CHAR. CLASS	METHODS					REACTION PLAN
			NO.	PRODUCT	PROCESS		PRODUCT/PROCESS SPECIFICATION/ TOLERANCE	EVALUATION/ MEASUREMENT TECHNIQUE	SAMPLE SIZE	SAMPLE FREQ.	CONTROL METHOD	
							If scratch can be felt with finger nail part is reworkable	Feel and Visual	100%	100%	Rework as per Standard Operation	Trim shop to rework
				Contamination to Surface			Not Acceptable	Feel and Visual	100%	100%	Book item through pre trim inspection	
							Less than or equal to 5 mm	Feel and Visual	100%	100%	Rework as per Standard Operation	Trim shop to rework
							Greater than 5 mm	Visual and Ruler	100%	100%	Raise Defect Note and place in on hold rack	Carry out Quality Investigation
				Resin Rich corners			Total surface area of 5 mm dia in any direction	Visual	100%	100%	Book item through pre trim inspection	
							Total surface area of >5 mm dia in any direction but <20mm	Visual and Ruler	100%	100%	Raise Defect Note	Trim shop to rework
							>20mm Reject Part	Visual and Ruler	100%	100%	Raise Scrap Note and place in on hold rack	Carry out Quality Investigation
				witness marks from mould			Not Acceptable	Visual	100%	100%	Book item through pre trim inspection	

CONTROL PLAN

☐ Prototype ☐ Pre-Launch ☑ Production

Control Plan Number Lola Composites Process	Key Contact/Phone Ken Preston 01480 359517	Date (Orig.) 13/05/2005	Date (Rev.) 13/05/2005
Part Number/Latest Change Level N/A	Core Team L Mayers, M Furness	Customer Engineering Approval/Date (If Req'd.)	
Part Name/Description Production Laminating	Supplier/Plant Approval/Date	Customer Quality Approval/Date (If Req'd.)	
Supplier/Plant / Supplier Code	Other Approval/Date (If Req'd.)	Other Approval/Date (If Req'd.)	

PART/ PROCESS NUMBER	PROCESS NAME/ OPERATION DESCRIPTION	MACHINE, DEVICE, JIG,TOOLS, FOR MFG.	CHARACTERISTICS			SPECIAL CHAR. CLASS	METHODS					REACTION PLAN
			NO.	PRODUCT	PROCESS		PRODUCT/PROCESS SPECIFICATION/ TOLERANCE	EVALUATION/ MEASUREMENT TECHNIQUE	SAMPLE SIZE	SAMPLE FREQ.	CONTROL METHOD	
							Flaw up to 20mm	Visual and Ruler	100%	100%	Raise D Note Rework as per Standard Operation	Trim shop to rework
							>20mm Reject Part	Visual and Ruler	100%	100%	Raise Scrap Noteand place in on hold rack	Carry out Quality Investigation
				Uncured Laminate			Fully Cured Part	Visual	100%	100%	Cure log, Check sheet, Standard Operation	Inform Team Leader and Investigate

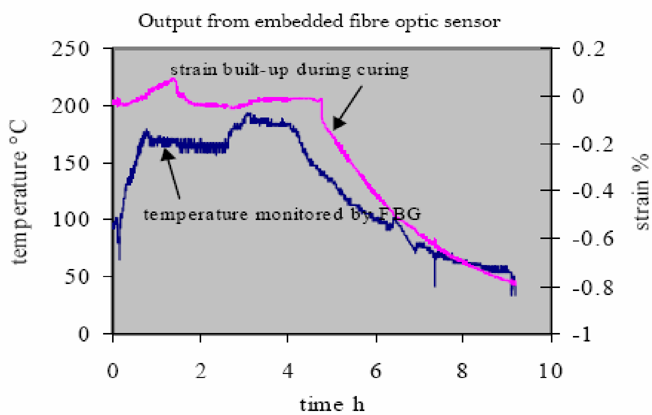
Appendix 7

Literature highlighting some of the constraints in techniques available for in-process control

Composite Manufacturing - Processing Measurements (CPD4B)

The mechanical properties of composite materials are significantly affected by the degree of resin cure. Efforts have been made in the past to understand resin cure mechanisms, chemical structures and resulting physical and mechanical properties. A variety of techniques have been developed to shed light upon resin cure and structure. The extent of thermoset matrix cure can be readily measured in laboratory tests but it is not yet common for 'online' or 'in-tool' techniques to be used in a production environment. AEA Technology carried out the current investigation during 1998, over a six-month period. Two reports were issued and a series of industrial visits were made to discuss some of the implications and arising issues.

In tool techniques	Post Fabrication Techniques
dielectrometry	thermogravimetric analysis (TGA)
ultrasonic property measurements	differential scanning calorimetry (DSC)
internal temperature measurement with thermocouples	dynamic mechanical analysis (DMA)
	torsional pendulum damping
embedded optical wave guide sensors	hardness (e.g. Barcol hardness)
electrical resistance	mechanical properties
refractive index measurements	solvent resistance
acoustic waveguides	dye colour changes
thermal conductivity	



The changes that occur in thermosetting matrix resins during composite processing can be assessed using a variety of techniques. The literature review focused on those techniques which have the greatest potential for on-line monitoring applications. The principal methods of monitoring resin cure are based on thermal effects, ultrasonics, dielectric/ electrical, optical and mechanical methods. Thermal and mechanical schemes are not applicable to on-line measurements. Many of the remaining schemes require a probe to be placed, and left in place, in the composite and involve complex equipment and information processing. Apart from methods, which assess the level of certain critical chemical groups, all the methods need calibrating, usually by DSC measurements, to relate the signal observed to the degree of cure. Unfortunately the calibration is not absolute and will vary with the type of resin and possibly from batch to batch of the same system. The interpretation of the output signal, to indicate when cure has finished, for example, may be difficult without a lot of experience of the monitoring method and of the behaviour of the resin system.

The review identified available equipment for assessing degree of cure during fabrication. There appear to be many promising techniques but only a few products available commercially. The instrumentation and sensors suitable for real time use in composite manufacturing are based on micro-dielectrometry, acoustics and electrical measurement. Sensors have been designed for use either in the tool or integrate within the composite component. Other techniques, such as those based on fibre optics, are in development. One of the more promising techniques is based on in-core fibre Bragg grating arrays. An added advantage of these systems is that they can also be used for subsequent component health and lifetime monitoring. No one technique is able to give all the required state of cure information. Most techniques rely on the measurement of a secondary property such as viscosity, speed of sound or electrical conductance from which the degree of cure / state of matrix resin chemistry is deduced. There is a requirement for low cost instrumentation and sensors that can be used to monitor aspects of the curing process. In the short term the equipment commercially available will have severe limitations and the development focus will probably remain in the more traditional area of process control. Any cure monitoring method adopted must be selected with the materials, process and end use of the composite in mind, to achieve optimum and economic results. Unfortunately, there is still no simple and inexpensive go/no go device available yet on the market.

ESR Technology

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