USING QUALITY IMPROVEMENT METHODOLOGIES TO ENHANCE CROSS DEPARTMENTAL COLLABORATION AND QUALITY COST REDUCTION

by

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B.S.E. Mechanical Engineering, Princeton University, 1999

Submitted to the Department of Mechanical Engineering and the Sloan School of Management in partial fulfillment of the requirements for the degrees of

Master of Science in Mechanical Engineering
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ABSTRACT

The research and project implementations described in this study took place during a seven-month period in 2004 at a distribution transformer factory in Germany. The purpose of this research is to show how quality management tools were used to break down functional business barriers and spread the responsibility for quality improvement throughout the local factory organization. A Cost of Quality (CoQ) analysis was used to diagnose the factory's main problem areas and prioritize the ensuing improvement efforts. Based on the analysis results, projects were developed that focused on reducing expenditures associated with failures found internal to the factory. These projects included: redesigning the failure resolution process to improve documentation practices and root cause analysis, implementing a First Pass Yield metric to help reduce the number of revisions generated by the Engineering and Order Management departments, and implementing a process-focused problem solving methodology to reduce Partial Discharge failures (the site's most costly internal quality failure). Each of the aforementioned projects required collaboration from multiple departments, and tools were implemented to facilitate process improvements and cross departmental communication. The ultimate goals of these initiatives are to decrease failure costs, reduce waste and increase the profitability and competitive position of the factory's transformer product.

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CHAPTER 1 - INTRODUCTION AND THESIS OVERVIEW

1.1 Introduction

The research and project implementations described in this study took place during a seven-month period in 2004 at a distribution transformer factory in Germany. The factory is a wholly-owned company of the Powercomp Group. "Powercomp" is a fictional name given to the company to protect its confidentiality and the transformer factory will be referred to simply as "Fabrik5". This chapter provides a document overview along with company and product information to establish a context for the research. A basic familiarity with transformer design and technical operations is assumed for readers of this thesis.

1.2 Thesis Overview

The purpose of this research is to show how quality management tools were used to break down functional barriers and propagate the responsibility for quality improvement throughout a local factory organization. These tools were applied to address several of the factory's most costly quality problems.

The thesis is organized as follows:

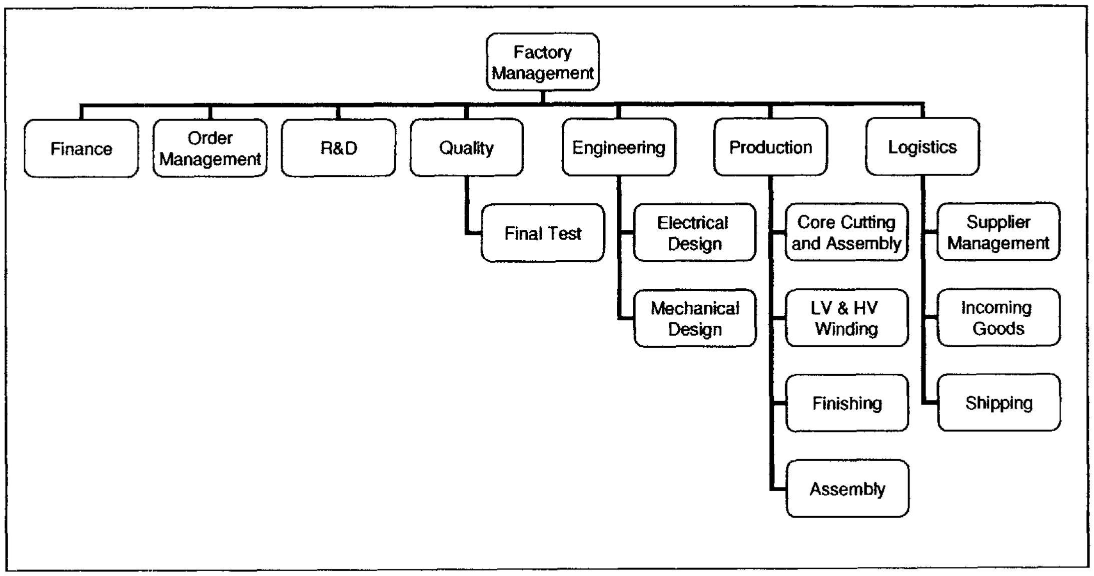
- **Chapter 1** provides a context for the projects by describing the company's background, organization and product.
- **Chapter 2** defines the Cost of Quality (CoQ) analysis used to provide a common framework to quantify the impact of quality on the organization. The results of this analysis are used to determine the cost-reduction projects described in Chapters 3, 4, & 5.
- **Chapter 3** defines an improved failure resolution process and describes the development of a computer-based application designed to facilitate the documentation and tracking of quality failures.
- **Chapter 4** describes the implementation of a First Pass Yield metric to help measure the quality of processes in the Order Management (Sales) and Engineering organizations.

- **Chapter 5** illustrates the development of a standardized production manual for the High Voltage Winding Area in an effort to apply a process-based approach to address Partial Discharge, the factory's most costly technical failure.
- **Chapter 6** summarizes the impact of each project, outlining benefits, risks and recommended future work. The chapter also addresses the transferability of the projects to other companies within Powercomp.

1.3 Company Description

The Powercomp Group is a global leader in power technologies and is a product of numerous mergers and partnerships. Fabrik5 belongs to the Transformers sub-division of Powercomp. The Transformers sub-division sells a variety of products ranging from single-phase transformers to small, medium and large distribution transformers. Within this product mix, Fabrik5 manufactures high-end distribution transformers. The factory has annual revenues of approximately $90 million US and employs approximately 400 people. The basic organizational structure for the factory is shown in Figure 1.1. Personnel from Research & Development (R&D), Engineering, Production, and Logistics all sit in one large room directly adjacent to the factory. Order Management, Finance and the Factory Manager are also within close proximity. There are no cubicles and news travels extremely fast. If there is a failure on the production floor, members from each team can quickly convene to address the immediate problem.

Figure 1.1 Factory Organization



Fabrik5 has been under increasing pressure to improve profitability. Prior to the start of this research study, the factory began the implementation of a pull-production system in an effort to decrease costs, throughput time and work-in-process inventory. Despite these efforts, several external factors made substantial cost reductions difficult:

- **Labor Cost:** Fabrik5 transformer processing requires significant touch labor and Germany has one of the highest hourly compensation costs in Europe. See Table 1.1.
- **Product Volume:** Powercomp instituted a "Focused Factory" program and product lines were consolidated into specified factories across continents. Fabrik5 was designated the Focused Factory for dry-type - transformers and became Powercomp's sole supplier for this product in Europe, Africa and the Middle East. The factory's other product lines were either sold or moved to Focused Factories elsewhere in the organization. This initiative led to a significant workforce reduction in the factory and the net loss in product volume left much of

Table 1.1 Indexes of hourly compensation costs for production workers in manufacturing, U.S. Bureau of Labor Statistics

Country	2003 Index
United States	100
Denmark	146
Norway	144
Germany	**136**
Switzerland	127
Belgium	126
Finland	124
Netherlands	122
Austria	116
Sweden	115
Luxembourg	105
France	96
United Kingdom	93
Ireland	87
Italy	84
Spain	68
Portugal	28
Czech Republic	21

the facility underutilized. This has increased the relative overhead allocation to the product and reduced overall productivity.

- **Product Scope:** The Focused Factory initiative has also made the factory less able to balance potential fluctuations in the distribution transformer market with other products.

1.4 Product Description

Fabrik5 manufactures high-end dry-type distribution transformers with power ratings ranging from 50 to 40,000 kVA. Dry-type transformers do not require liquid dielectrics and are typically used in applications where human and environmental safety is critical. These include high-rise office buildings, nuclear power plants, offshore petrochemical platforms, ocean vessels and industrial process plants. Figure 1.2 shows a typical three-phase transformer, although size and weight can vary significantly. These transformers can weigh anywhere from 300 kg to 20 metric tons. The factory offers several complementary options including environmental enclosures, air and water-based cooling systems and on-load tap changers.

Figure 1.2 Typical dry-type, 3 phase transformer

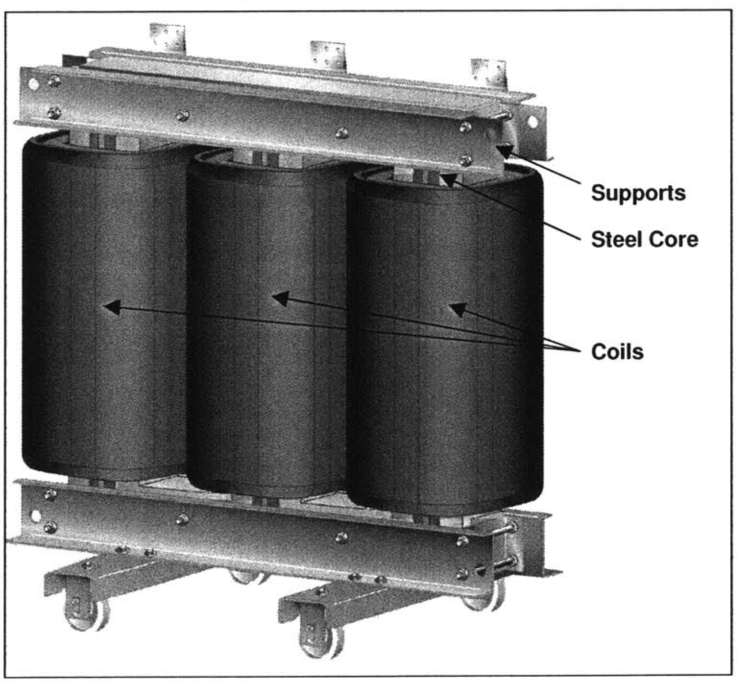
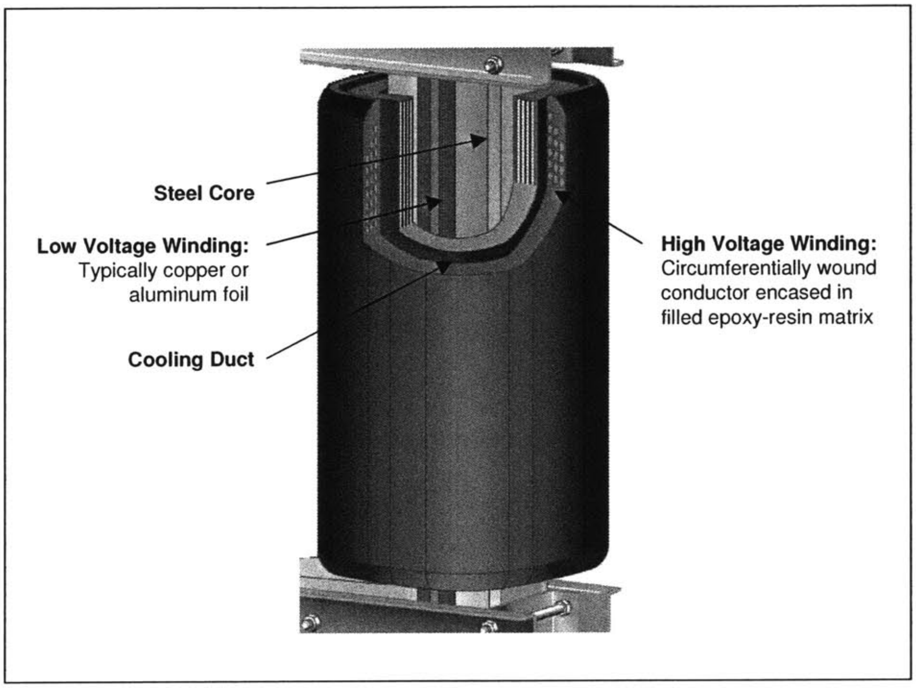


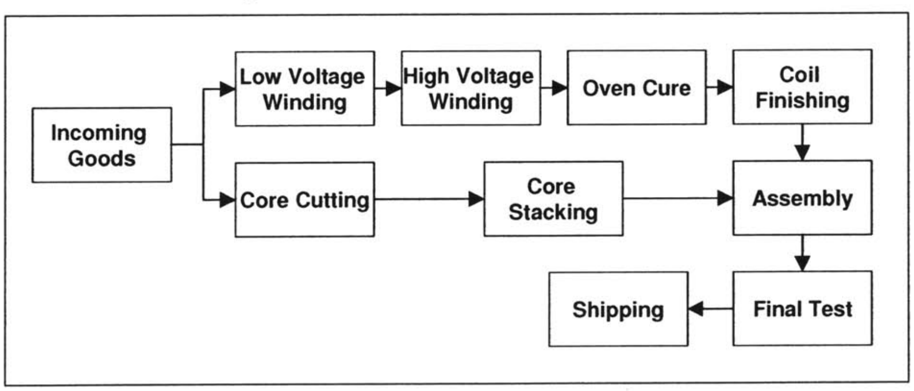
Figure 1.3 shows a typical cross-section of a coil winding. As shown, the conductor is embedded in a filled epoxy-resin matrix. Coil diameter, length, conductor layer configuration and the number of cooling ducts vary depending on customer requirements.

Figure 1.3 Typical Coil with Cross-Section



The factory's transformer production process is shown in Figure 1.4. With the exception of Core Cutting and Oven Cure, each step requires significant touch-labor which contributes to the current cost challenges of the factory.

Figure 1.4 Transformer Production Process



1.5 The Role of Quality

A rigorous analysis of the market's perception of product quality is outside the scope of this thesis. However, Fabrik5's product literature heavily emphasizes their commitment to quality, using words and phrases such as "robust", "safe", "reliable", "highest precision" and "designed to fulfill the most exacting specification requirements." The factory also advertises ISO 9001/14000 certifications and conformance to various International Electrotechnical Commission (IEC) and other standards.

Interviews with factory management confirm the hypothesis that the factory relies on superior quality, both in technology and in timeliness of delivery, to attract and retain customers. Several impediments toward meeting this goal were observed by the author:

- In 2003, a significant amount of total production labor was allocated to rework. Since many of a transformer's key performance characteristics cannot be measured until the product is fully assembled, failures introduced early in the production process consume valuable downstream resources prior to being discovered.
- The failure rate due to Partial Discharge (PD), an electrical phenomenon that could seriously impact transformer performance, has been increasing. The cost to repair a transformer due to PD is high and the company had yet to find a consistent root cause.
- Order Management stated that 20-25% of customers require on-site Final Acceptance Testing, where customer representatives witness Final Test processes. Customers witnessing failures of any type during Final Test could potentially erode brand confidence.

Even though the majority of failures were caught while the transformers were still in the factory, rework issues introduce unplanned delays both to the current work in process and order backlog. The company's competitive position and profitability can be improved by reducing these delays.

CHAPTER 2 - COST OF QUALITY ANALYSIS

2.1 Introduction

This chapter describes the implementation of a quality cost model to provide a common framework from which the factory can quantify the effect of quality on the entire organization. With this perspective, cross-functional improvement projects could then be prioritized and implemented based on the perceived impact on long term costs.

2.2 Quality Cost Definitions

Campanella (1999) states that quality costs "represent the difference between the actual cost of a product or service and what the reduced cost would be if there were no possibility of substandard service, failure of products or defects in their manufacture." Any investment or resource allocated toward the prevention, verification, management or resolution of quality issues can be considered quality costs. These costs can be divided into four general categories (Juran and Gryna, 1980):

- **Prevention Costs**: Costs of activities intended to prevent poor quality in a product or service. These include design reviews, supplier reviews, quality improvement projects, or quality training and education.
- **Appraisal Costs**: Costs of measurements, inspections or audits designed to assure that a product or service is meeting quality and performance standards. These include material and dimensional inspections and verification tests.
- **Internal Failure Costs**: Costs resulting from failed products that are caught *before* delivery to the customer. These include labor and material costs associated with the repair, rework or scrap.
- **External Failure Costs**: Costs resulting from failed products that are found *after* delivery to the customer. These include warranty costs, product recalls and/or replacements, and time spent processing customer complaints.

Quality management at Fabrik5 had recently instituted a Cost of Poor Quality (CoPQ) program, which focused on the measurement and reduction of internal and external failure costs. Company literature also referenced the measurement of "Costs of

Conformance", which represent prevention and appraisal costs. This dual view gives managers a more complete picture of their quality program. In an extreme example, a company could drive their failure costs to zero by hiring a legion of quality inspectors who would ensure every step of the production process is performed to the highest standards. Although failure costs would be non-existent, astronomically high appraisal costs could have a greater negative impact on profitability. This trade-off is consistent with Juran and Gryna's (1980) view of quality costing. In contrast, Crosby (1979) believes that the optimal, or most cost effective, level of conformance is to have zero defects. Regardless of end-state philosophy, having a comprehensive view of quality expenditures can help managers better understand the impact of their investments while also presenting and prioritizing opportunities for waste reduction in any of the four categories. Campanella (1999) suggests that the basic strategy of a quality cost system is to:

- Understand and tackle failure costs in an attempt to drive them to zero
- Prioritize and invest in the right prevention activities to bring about improvement
- Reduce appraisal costs based on the results achieved
- Continuously assess and redirect prevention efforts for further improvement

2.3 Previous Applications

There is a host of academic and industry literature in the area of quality costing that present different models, methodologies, and case studies. Shah and Mandal (1999) perform a rigorous literature survey regarding the effectiveness of quality cost programs. Schiffauerova and Thomson (2003) also provide a summary describing different quality cost models and best practices. Hendricks and Singhal (1997) show that companies who have won awards for Total Quality Management (TQM) implementations have had higher relative changes in operating income when compared to various control sets. While the studies performed at Fabrik5 do not represent a formal TQM implementation, the techniques used in this analysis and in the following chapters employ tools that are commonly referenced in TQM literature.

The model chosen for Fabrik5's analysis was an extension of Powercomp's CoPQ initiative, which emphasizes "Costs of Non-Conformance" (internal and external failure costs) as well as "Costs of Conformance" (performance and appraisal costs). Powercomp's internal quality literature referenced Campanella's *Principles of Quality Costs* (1999) as a guide for detailing specific quality cost elements. Therefore, to build off of the company's current practices, this reference was used as the baseline for the analysis.

2.4 Model Development

Each quality cost category (Prevention, Appraisal, Internal Failure and External Failure Costs) can be broken down into more detailed cost elements. Plunkett and Dale (1987) believe that quality cost categories are dependent on the structure and technology of the enterprise. Appendix B provides a complete list of cost elements used in this study. For organizational purposes, each cost element was given a corresponding number prefix, with '1' indicating prevention costs, '2' appraisal costs, '3' internal failure costs and '4' external failure costs.

Several sources were used to generate the quality cost data. First, data was taken directly from the factory's Enterprise Resource Planning (ERP) system and accounting software. The ERP system kept cost records of past failures and warranty claims requiring formal work orders. Data such as the labor allocation for the Final Test department, machine depreciation, and departmental budgets was extracted from the accounting system with help from the controller. Other costs were estimated by conducting interviews with management and factory employees. The reliability of these estimates varied depending on interviewee, availability of data, and time. The following list highlights a few examples of how specific costs were calculated in Appendix B along with a subjective measurement of relative accuracy:

- **Highly Accurate** (company keeps detailed records)
  - 1.5.1 Administrative Salaries: Data was taken directly from the accounting software.

- 4.5 Liability Costs: The factory kept detailed records of amounts spent for product liability insurance and claims.

- **Moderately Accurate** (requires some analysis or time estimation)
  - 1.2.3 Product Design and Qualification Tests: The factory's cost accounting methodology allocates specific machines and their depreciation to specific departments such as R&D. There are also budgets established for formal projects such as the development of a new epoxy system. Based on interviews, it was estimated that 25% of both machine time and project focus were allocated toward addressing quality issues.
  - 3.3.2 Operations Rework and Repair Costs: Using data from the ERP system, a root cause analysis was generated categorizing all failures requiring a formal work order to purchase additional materials or to allocate development/production hours to resolve the problem. It was possible to distinguish work performed on failures found in the factory and work performed to address warranty issues, and detailed cost data was available for these entries. However, specific categorizations had to be inferred from the general failure descriptions.
- **Less Accurate** (requires several assumptions, based on averages)
  - 2.2.4 Process Control Measurements: This is the sum of different tests performed during transformer manufacture such as a 'Gelling Test' to verify coil cure properties, along with various electrical tests during transformer assembly. Several estimates are required including an average time per test, average number of transformers produced per year, and an average cost of labor per minute. A sample cost calculation for the Gelling Test would be:

$$\text{Cost} = \left(2\frac{\text{min}}{\text{coil}}\right)*\left(3\frac{\text{coils}}{\text{trans}}\right)*\left(3000\frac{\text{trans}}{\text{year}}\right)*\left(\frac{\dfrac{\text{Total Labor Cost}}{\text{Prod Dept}}}{34\dfrac{\text{Employees}}{\text{Prod Dept}}}\right)*\left(\frac{1\text{ Employee}}{220\dfrac{\text{days}}{\text{year}}*7.5\dfrac{\text{hrs}}{\text{day}}*60\dfrac{\text{min}}{\text{hrs}}}\right)$$

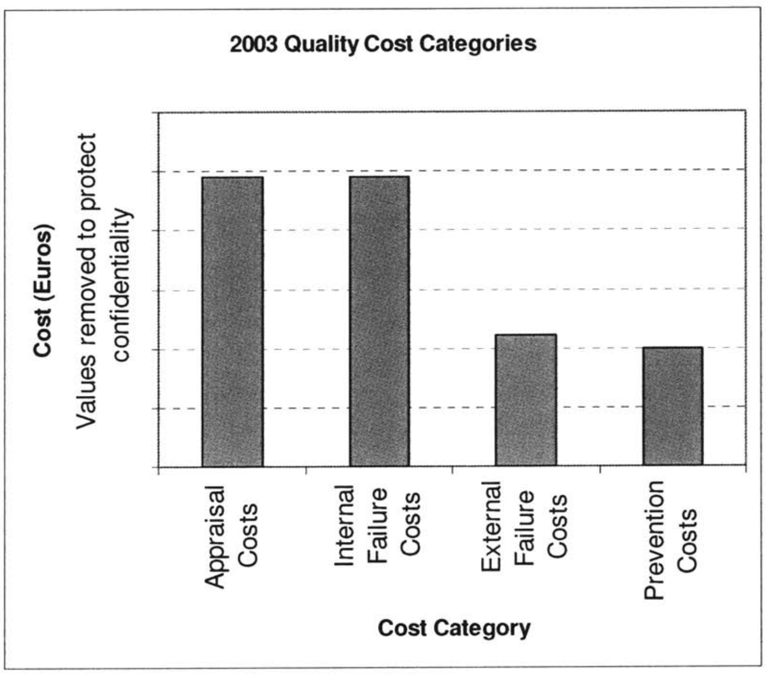
- **Ignored** (extremely difficult to estimate or not directly applicable)
    - 4.8 Lost Sales: The factory sells the majority of their transformers through Powercomp corporate intermediaries. This extra degree of market separation makes it difficult to quantify the effect of lost sales without significant market research. Shah and Mandal (1999) state that the single largest measurement problem in quality costing is that associated with lost sales or customer dissatisfaction.
    - 3.3.4 Extra Operations: During the HV winding process, much of the operation is spent adjusting conductor placement and fitting supports in conjunction with coil winding. Steps required for production and those required for quality assurance are often indistinguishable.

Based on the above subjective categorizations, approximately 55% of measured costs were considered "Highly Accurate", 33% "Moderately Accurate" and 12% "Less Accurate". The majority of the measured quality costs were based on inputs pulled directly from the factory's ERP or accounting software.

2.5 Project Analysis

A series of Pareto diagrams were developed from the quality cost model to visualize the key cost drivers and prioritize areas where immediate projects would yield the most benefit. A diagram of the four cost categories can be found in Figure 2.1. The actual cost values have been removed for confidentiality purposes, but the relative magnitudes are accurate. As shown, Appraisal Costs and Internal Failure Costs represent areas of highest expenditure.

Figure 2.1 Quality Cost Categories for 2003

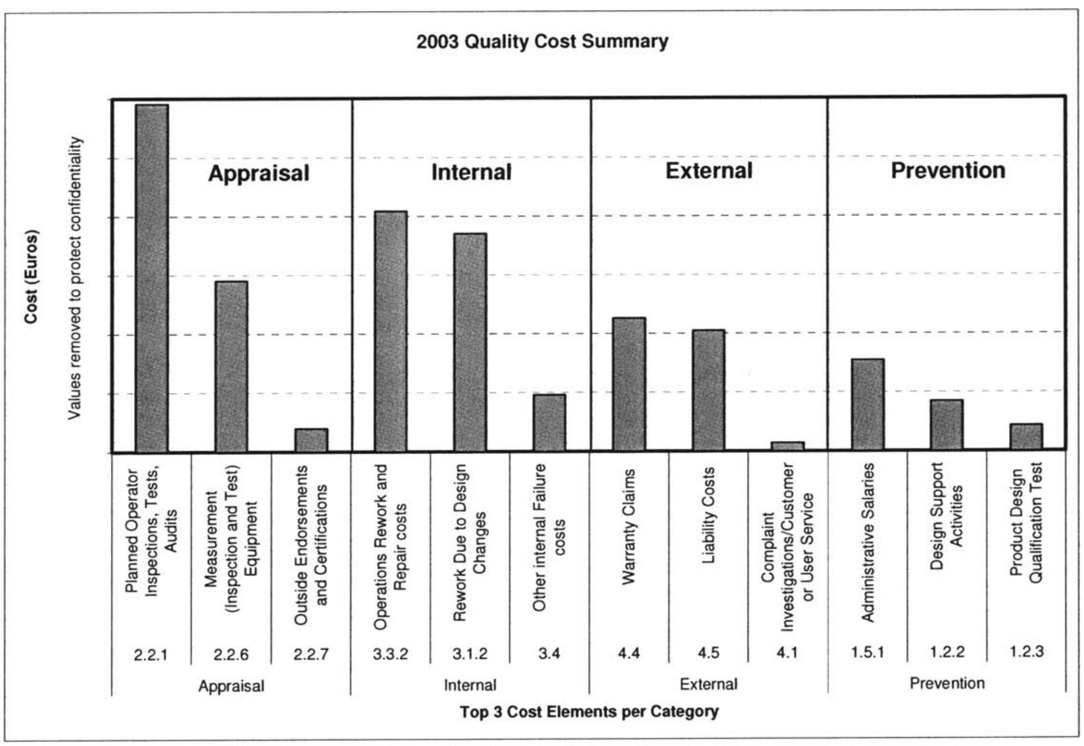


A more specific breakdown of each cost category is made in Figure 2.2, where the top three cost contributors in each category are displayed:

- Appraisal Costs: The majority of these costs come from labor and capital equipment in the Final Test Department. This makes sense because with Fabrik5's current technology, most of a transformer's key performance characteristics cannot be evaluated until the device is fully assembled.

- Internal Failure Costs: It can be inferred that rigorous final testing enables the factory to catch many of their product quality problems prior to shipment. Internal failure costs are dominated by rework and repair costs.
- External Failure Costs: Approximately one half of the Warranty Claims element was due to one particular customer issue. The liability of this failure was still in question and the event was deemed an "anomaly" by factory management. Much of the Liability Costs element represents various forms of insurance required by corporate or state authorities.
- Prevention Costs: Shah and Mandel (1999) indicate that these costs are typically the smallest component of the overall quality cost model. The current breakdown supports the claim that Quality and Engineering administrative activities typically dominate this category.

Figure 2.2 Quality Cost Breakdown for 2003

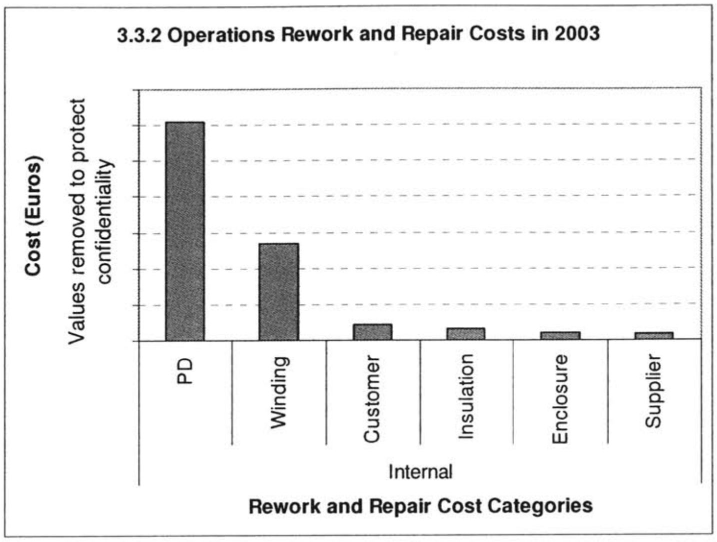


Reviewing the results with factory management, it was agreed that the first round of projects should address internal failure costs. These areas had more visibility to factory employees and it was perceived that investments in this category would offer a higher probability of return when compared to appraisal costs. Interviews with company employees confirmed that an analysis to evaluate efficiencies in the Final Test department should be performed at a later date.

As shown, the top two components of Internal Failure costs were "Operations Rework and Repair Costs" and "Rework Due to Design Changes". A root cause analysis was performed within each element to further understand the cost drivers:

- 3.1.2 Rework Due to Design Changes: Existing documentation was not sufficient to further clarify the root cause behind this issue. Interviews with Production indicated that Engineering frequently made errors on production drawings. Engineering suggested that Order Management was responsible for changing the design because insufficient information was solicited up-front prior to closing the deal for an order, especially for custom designs. There is a perception that Order Management does not penalize customers enough for making changes after production has started. Order Management states that the changes simply reflect changing customer requirements. There was no way to determine which group was responsible for a particular change and this contributed to internal political tensions.
- 3.3.2 Operations Rework and Repair Costs: As shown in Figure 2.3, the majority of documented failures occur from an electrical problem known as Partial Discharge (PD) which will be described further in Chapter 5. Since PD primarily occurs in the High Voltage winding, an effort to address issues in Partial Discharge may also mitigate other failure modes in the Winding category.

Figure 2.3 Operations Rework and Repair Costs



During the course of the root cause analysis, it was difficult to determine the cause of many failures due to the factory's methods of failure documentation. Often, the documentation would only list a generic sentence describing the failure. This was enough to assign fault to a particular department, but insufficient in giving an indication as to the nature of the failure. Was it an employee error? Was the machine calibrated incorrectly? Were the customer requirements inputted correctly? This ambiguity made performing a more thorough root cause analysis difficult in the areas of Design Changes and Winding failures. Despite having a factory with seemingly efficient internal communication, it was also difficult to retrospectively determine what type of improvements had already been implemented and whether or not these improvements had been effective.

In summary, three focus areas emerged from the Internal Failure component of the quality cost analysis:

- Improve the documentation of failures with the goals of establishing more insightful failure analysis and better management of corrective action projects. This initiative will be the focus of Chapter 3.

- Establish a framework to monitor the Order Management and Engineering groups that will help identify process quality issues and help reduce the number of changes in each organization. This initiative will be the focus of Chapter 4.
- Reduce rework due to operational issues in the High Voltage Winding department. This will be the focus of Chapter 5.

2.6 Cost of Quality Summary

Prior to the start of the research project, consultants and the managers in the factory compiled a less detailed analysis only categorizing their internal failure expenditures based exclusively on work order data pulled from their ERP system. This gave similar results to the quality cost analysis described earlier in this chapter. Even without the analysis, the management team already knew that Partial Discharge was one of the factory's largest internal problems. What was the value of building a more detailed model of their quality expenditures? Shah and Mandal (1999) summarize that the primary uses for quality cost data are:

- **To provide attention to management for quality improvement:** Translating quality into monetary terms can help give management a clearer view of problem areas (Juran, 1999). The exercise of compiling quality cost data also encouraged people in the factory to differentiate between time they spend addressing quality issues and value-added work in the customer fulfillment process. This gave more visibility to factory quality initiatives and spread the accountability for improvement across the local organization. The exercise also exposed deficiencies in current quality processes such as documentation practices.
- **To identify areas where corrective actions would be most profitable:** From the perspective of factory management, this research project is a 2004 Prevention Cost investment, falling either under Quality Program Planning or Quality Improvement (see Appendix B). The quality cost model was useful in conveying that this research project would be addressing areas where improvements can have a substantial positive impact. Also, the magnitude of expenditures in Appraisal Costs raised questions regarding Final Test operations which may be addressed in a future project. The model will be a useful resource for management to evaluate future investments in this area.
- **To measure performance:** If the factory continues to track quality costs, they can evaluate how their investments in quality improvement perform over time.

As previously mentioned, the majority of the cost measurements in the quality cost analysis were deemed either "Highly or Moderately Accurate." This makes sense because the results reflect the most readily available data. People generally gravitate toward simpler, more quantifiable measurements (Kerr, 1995). Although there is a risk that the analysis could be overlooking a substantial problem, the understatement of costs would most likely be in the External Failure Cost category. As previously mentioned, quantifying the impact of customer dissatisfaction or lost sales is one of the most difficult parts of the analysis. Shah and Mandal (1999) conclude that most firms adopt quality cost programs due to high internal failure rates, which was the primary management concern at the beginning of the research project. Regardless of whether the model accounts for 100% of the company's actual quality costs, sufficient information was available to initiate projects with a significant potential benefit.

CHAPTER 3 - QUALITY MANAGEMENT SYSTEM (QMS)

3.1 Introduction

This chapter describes the development of a process and computerized tool to facilitate the documentation and review of failures. There are several terms that will be used throughout this chapter, many of which are consistent with ISO 9001:2000 documentation practices. ISO 9001:2000 is an international standard that provides requirements for an organization's quality management system. In other words, the standard outlines what an organization should be doing to ensure that its products or services meet their customer's quality requirements and comply with applicable regulations (ISO 9000:2000). For a failure resolution process, several main components are defined as follows:

- **Problem Description:** This represents a thorough description of the failure and surrounding circumstances.
- **Disposition:** This is the action performed to address the immediate failure situation. For example, if a transformer coil is damaged, this would be the action performed on that specific coil to prevent the defect from being transferred to the customer. Examples include repairing the defect, reworking the coil back to original specification, or scrapping the coil.
- **Corrective Action:** This is the action performed to prevent the recurrence of a specific failure in the future. Changing processing techniques, modifying the engineering design or implementing quality education would be examples of corrective action.

3.2 Problem Description

In developing the quality cost model, it was difficult to retrospectively determine the root cause of many failures. For a recent failure in 2004 requiring significant expenditures in materials and rework, the only description of the event was *"Spule Neu, Kern Neu,"* which translated means, "New coil, new core." Interviewing various managers and employees, the details of the actual failure were not clear and no one knew what was done to prevent it from happening again. To gain a broader perspective, the failure resolution process was mapped and several areas for improvement were observed:

- **Scope:** Failure documentation was limited to test failures and those found on the production floor. Departments such as Supply Management did not have any formal mechanisms to track quality issues.
- **Failure documentation:** Table 3.1 describes the primary mechanisms by which failures were documented in the factory, including primary benefits and limitations.

Table 3.1 Documentation Methods

Method	Description	Benefits	Limitations
Enterprise Resource Planning (ERP) System	Formal work orders generated to perform rework	Tracks material, labor and development costs associated with a failure.	Generic, often ambiguous failure descriptions; does not track corrective actions. Only tracks failures in production or test requiring a formal work order.
Quality Report Viewer Tool	Microsoft® Access-based tool used to document failures found during Final Test.	Pull-down fields for failure type, location and cause; has text-based fields to fill in a more detailed problem description and solution.	Only applies to failures found in test; fields are often left empty; tool performance is poor when multiple users access system.
Quality Cards	Data collection for measurement and statistical purposes	Tracks performance of key indicators such as winding turns, no-load losses, impedance and coil diameter	Does not address individual failures nor record the impacts of rework
Failure Reports	Formal technical memos or quality reports detailing larger problems.	Comprehensive root cause analysis	Not used for smaller failures and are limited to availability of Quality Manager.
Customer Complaint Reporting Program	Required by Powercomp to record customer complaints and track their resolution	Helps in tracking External Failures	Separate system with little visibility from factory.

- **Process Documentation:** Per ISO 9001 requirements, quality management had defined and documented processes addressing issues related to product conformity. These included the collection of quality statistics, the handling of failed materials, and corrective action processes. However, in comparison to other Powercomp facilities, these process descriptions were vague and it was not apparent that the written descriptions were put into actual practice.

- **Visibility:** Although failure reports, quality statistics and process documentation were kept on public folders on company servers, they were not usually accessed by people in groups other than quality management and development. There was an instance where a bushing was damaged during transport operations. The bushing was replaced, but when an employee was asked if any documentation was made, the reply was, "no, because the Quality Manager is not here." The failure resolution process should have more visibility in the factory.
- **Accountability:** The factory has a small management team and problems are often resolved quickly. However, it was observed that they often had difficulty keeping track of projects and who was responsible for completing the required actions. Many good ideas were generated during brainstorming meetings, but the follow-up management needed improvement.
- **Knowledge Base:** The current Quality Manager had over 40 years experience as an employee of Fabrik5. Much of the factory's quality resolution was based on his direct involvement and knowledge. Since he was approaching retirement, much of his knowledge of past failures and resolutions would be lost. Documentation needed to be improved to facilitate the transition of the knowledge base within the company.

3.3 Internal benchmarking

The quality practices of four other factories within Powercomp were benchmarked with the goal of generating a set of best practices and potential improvement areas for the Fabrik5 factory. Quality managers from these facilities were interviewed and the factory was given access to samples of their process documentation.

These factories varied in size and product scope. For example, a larger factory with more advanced technology had their quality processes fully integrated with the company intranet. Detailed process instructions could be accessed from any site computer and metrics were largely automated. However, this system was extremely expensive and took several years to build and implement. Other factories had developed simpler internal tools such as spreadsheets to meet the specific needs of their quality managers. Training site employees to use these tools enabled those closest to the failures to initiate the failure resolution process even if the Quality Manager was not available.

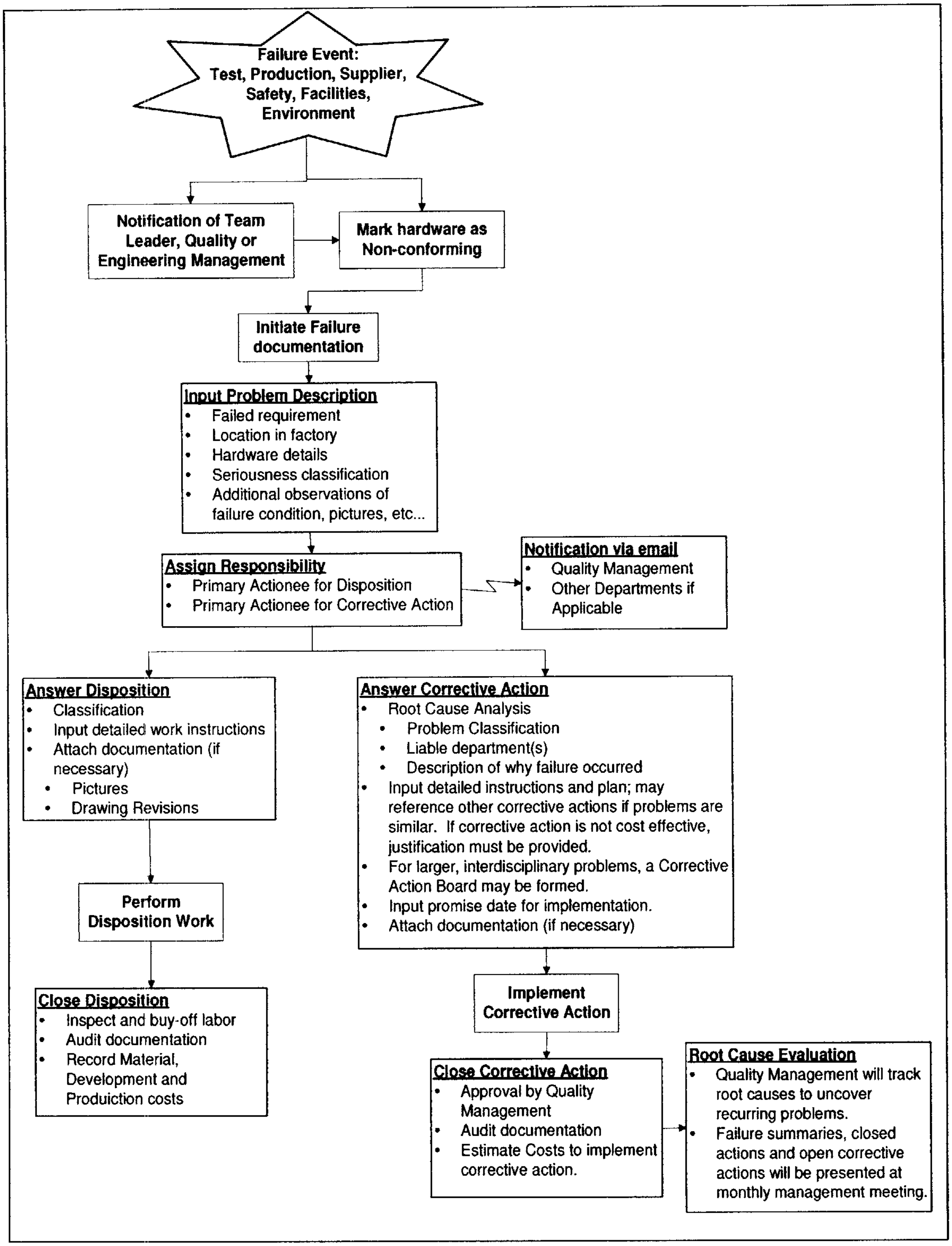
Many of process documents received from these factories needed to be translated into English from several other languages so the author could understand and compare the documentation. This was time consuming and reduced the accuracy of the comparison. However, much of the verbiage was consistent with ISO 9001 so this improved the clarity of the translations. In spite of the language challenge, it was evident that Fabrik5's process descriptions included the least amount of detail of all the factories evaluated.

The benchmarking process was limited to interviews and document evaluation. The extent to which the interviewed managers had implemented their processes as stated could not be determined. However, the comparative insights were useful in choosing improvement areas appropriate for the factory.

3.4 Process Description

Based on the benchmarking results, an improved failure resolution process was defined with the goal of documenting 100% of internal and external failures. See Figure 3.1 for the general process description. For each failure, the new process defines one *Problem Description*, its *Disposition* and the *Corrective Action* taken.

Figure 3.1 Proposed Failure Process Model



When the new process was presented to factory managers, the response was, "this is no different than the process we currently have." This statement may have been true, but only for *some* failures through *informal* communication channels. The new process presents improvements in several key areas:

- **Scope:** Failures can be documented for test, production, supply management (defects in incoming materials), facilities (materials in house, machine failures), safety and the environmental issues. The old process only focused on test and production.
- **Documentation:** For every failure, standardized records will be kept describing the problem (Problem Description), what action was taken with the failed hardware (Disposition) and what action was taken to prevent the problem from recurring (Corrective Action). The documentation must then be approved by Quality Management to ensure compliance with ISO 9001:2000 standards. This facilitates process accountability in Quality Management.
- **Visibility:** When a failure occurs, initial management notification is not required and failure documentation can be initiated by anyone at any level in the factory. However, once the failure is recorded, follow-up is required by Quality Management.
- **Accountability:** Formal responsibility is assigned for both the Disposition and the Corrective Action. Keeping individuals accountable for open actions will ensure the problems get addressed. Promise dates for corrective actions also facilitate the project management for quality improvements.
- **Knowledge Base:** Having detailed, accessible records allows employees and managers to become more familiar with the factory's problem areas. The process can help retain the detailed knowledge of management and factory personnel.

3.5 QMS Implementation

An interactive software application and database were developed to support the failure resolution process described in Figure 3.1. This section will go into some detail regarding the software implementation process and program features, but this section's main purpose is to explain key decisions and to show how the tool addresses the needs of the local factory.

During the seven month research period, the factory was in a transition phase where the existing Quality Manager was retiring and there was a significant risk that his replacement would not start at the company prior to the completion of this study. To facilitate the chances of project sustainability and knowledge transfer, the decision was made to build a computer-based system with the quality processes embedded into the program's functionality. This would facilitate failure documentation during the transition period and provide the new manager with a functional tool upon his/her arrival.

Choosing a data structure familiar to the factory was an important component of the project value proposition. When deciding the medium for tool development, several options were considered:

- **Modify existing Quality Report Viewer program:** This program was already in use by Final Test and expanding the program's functionality would be a quick and easy solution. However, this system limited the number of simultaneous users and could not be integrated into the factory's main database. IT indicated that the tool was due for an overhaul.
- **Modify ERP system to accommodate new fields and database capability:** Only one person in the company was familiar with the ERP programming language and external consultants would likely be involved. This option seemed time-consuming and expensive with limited flexibility in both development and long term maintenance.
- **Build an application from scratch:** Although this would require more up-front planning in terms of data structure, using a common development environment

such as Visual Basic® was common practice in the factory. This method also enabled full compatibility with the company's existing database system. Several previous tools in Engineering and Final Test had been developed in this manner

The decision was made to build a customized, bi-lingual Visual Basic® application. Options were explored for outsourcing the programming work, but the necessary expertise was available internally, adding speed and flexibility to the development effort. Information Technology (IT) resources were limited and it was unlikely a significant programming effort would be initiated after study completion. Therefore, with guidance from IT, the author performed much of the programming to ensure that significant technical progress would be made prior to the author's departure. This decision increased the chances for project sustainability.

Prior to study completion, a beta version had been presented to factory management and was being tested by selected employees. The interface with the main failure documentation screen is shown in Appendix C. For each failure, there are inputs for the Problem Description, Disposition and Corrective Action. Several key attributes are noted:

- **Scope:** The user is given options to create failures pertaining to *Transformers* (TFO*), Purchase Orders* (PO) or *General* failures such as materials, facilities, safety and environment.
- **Process Integration:** Pull-down menus, text fields, or other controls are available for every input required for the process outlined in Figure 3.1. During program operation, bi-lingual help instructions appear whenever the mouse is dragged over a particular input.
- **Tool Consolidation:** The program replaced the Quality Report viewer tool, providing a form for Final Test to document test results. The ERP system will still be used to initiate work orders, but the QMS program will be used as the primary failure documentation tool. It can also be used in conjunction with the Customer Complaint Reporting Program.

- **Language:** The application is bi-lingual, allowing users to toggle field names and 'Help' documentation between German and English. It would be relatively easy to convert this application to other languages using the Latin alphabet.
- **Notification:** Quality Management is automatically notified via email whenever a failure is initiated. The management team can also be notified for more serious failures.
- **Accountability:** Pull-down menus are presented to assign Disposition and Corrective Action responsibility, as well as formal approvals for work instructions, work inspection and/or documentation for each major step in the process.

3.6 Summary and Future Work

The purpose of the Quality Management System is to provide a means to effectively document and review failures. Choosing a programming structure familiar to the factory was an important component because it enabled quick, iterative development along with a smooth project transition at the conclusion of the research project.

Although it was agreed that the development of an automated system would be the most sustainable approach, there are a few risks:

- An automated system requires IT maintenance: Bugs will inevitably arise as more of the program functionality is explored and IT resources are required to complete the program implementation. This risk was mitigated by the development of a programming guide, outlining the program's organization, functions, key variables, and other distinctions. A list of open items was also compiled to smooth the technical transition to IT management.
- The new Quality Manager may choose not to implement the proposed process. This tool was received well by on-site employees, especially in the area of Supply Management where they previously did not have a formal documentation mechanism. The tool's paperless nature simplifies failure management and enables more people within the company to provide input. Also, programming in

Visual Basic® offers flexibility for the new quality manager to make changes as necessary.

- With limited management resources, the documentation of every failure might overwhelm the group with open Disposition and Corrective Action requests. Approximately 300 failures were documented in 2003, but more failures will likely be documented due to the increase in process scope. It will be at the discretion of the Quality Manager to determine the level of follow-up required depending on the seriousness of the failure and its impact on quality costs. For larger corrective action projects, initiatives may be combined as long as the reference is formally documented.

Along with continual debugging and incorporation of factory feedback, further work needs to be completed in the development of printable analysis reports to summarize trend information from QMS database. Suggested metrics and formats were recommended, but the final structure will be organized depending on the needs of the new Quality Manager.

CHAPTER 4 - FIRST PASS YIELD (FPY)

4.1 Introduction

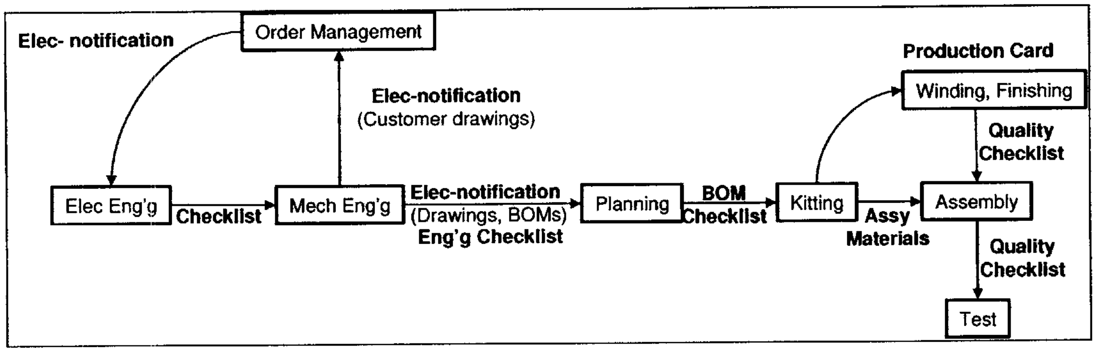
This chapter describes the implementation of a First Pass Yield metric to help measure the quality of the Engineering and Order Management processes. Having a consistent measurement and analysis framework will help generate a discussion between the groups to address why certain orders have high numbers of revisions. The reduction of revisions will help reduce quality costs associated with "Rework Due to Design Changes."

4.2 Problem Description

The "Rework Due to Design Changes" category is described as unplanned material, manufacturing or development costs incurred by design/drawing errors or requirements changes after the production process has begun. A transformer design is formally owned by the Engineering organization, but the Order Management group has significant impact on the defined requirements. As product-specific materials are purchased and transformers progress through manufacturing, late-stage changes pose a higher risk of scrap, rework and repair.

The typical order fulfillment process is shown in Figure 4.1 (Internal Documents, 2004). Order Management captures customer requirements and forwards them to Engineering through automated systems. The groups then work together to create a product quote. Once the order is finalized, engineering completes the electrical and mechanical design and forwards the documentation to planning and production. Once Supplier Management begins to order materials, changes introduced later in the process can dramatically impact quality costs.

Figure 4.1 Order Fulfillment Process



The descriptiveness of the factory's failure records was only sufficient to lump design changes into a general rework category. In an attempt to better understand how the Order Management and Engineering organizations impact quality costs, several questions arise: What is the nature of the change and who is responsible? When in the production process was the change introduced? Was there a typographical error on a production drawing? Did Order Management or Engineering make a mistake imputing or calculating design constraints? Was sufficient order information obtained when materials were authorized for purchase? Did the customer drive a requirements change and were they charged for the scrapped material and rework costs?

4.3 Context

The quality cost analysis reaffirmed the importance of several projects already in process prior to the beginning of this project:

- Product Checklists: Formal checklists were given to both the Order Management and Engineering organizations to ensure that adequate information was available before proceeding to the next step in the order fulfillment process.
- Paperless Office: Prior analysis had shown that a significant amount of engineering time was spent printing and distributing documents to be sent to suppliers and production. Computer code was written to generate an electronic archive of 'PDF' files specific to each department and function. Each file was given a formal revision number facilitating configuration management. The

archive also enabled the electronic transfer of files and permitted downstream recipients to print only what they needed.

- First Pass Yield (FPY): One of the goals of management was to have a comprehensive FPY metric implemented at each site in the Transformer organization. Consultants had proposed an FPY process for the factory, but the data gathering and implementation had not yet begun.

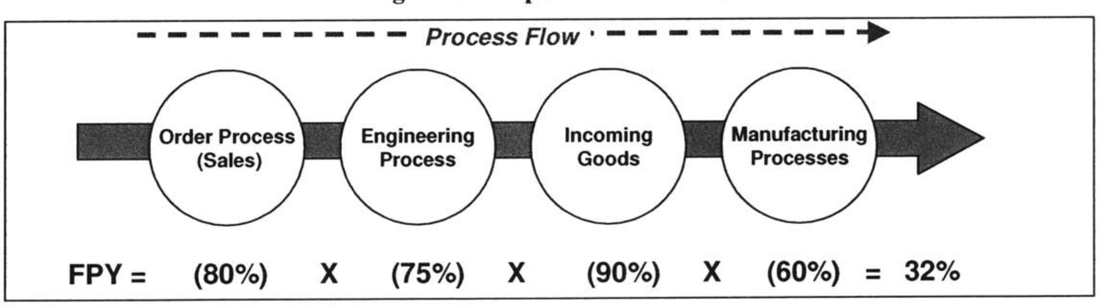
4.4 First Pass Yield

First Pass Yield (also known as 'First Time Yield') is the probability that a product or order will be processed without error. For a given process or step, a yield is defined as:

$$\text{Yield} = \left(\frac{\text{Total Units produced without Rework or Reject}}{\text{Total Units Produced}}\right) * 100\%$$

Per Powercomp quality goals, each factory shall determine the steps critical to their overall business process and establish data collection points for each step. To generate the comprehensive FPY metric for the factory, individual yields are then multiplied together representing the total probability that a unit has gone through the entire process without defect. See Figure 4.2 for the proposed process for Fabrik5 along with an example calculation. Although the calculation assumptions and processes will differ from factory to factory, establishing a local FPY baseline and tracking subsequent performance improves local and corporate visibility to the effectiveness of a factory's quality improvement efforts.

Figure 4.2 Proposed FPY Process



In an interview with a corporate Quality Manager, the following advice was given regarding the implementation of a FPY metric:

- Keep the metric simple and easily measured
- Establish ownership for measurement local to the process. For example, measuring manufacturing FPY should be done by those in manufacturing. This will help establish point accountability.
- Solving problems is the key, not the measurement! The initial metric can be "quick and dirty" with different segments being incorporated at different times. For example, if FPY in Order Management can be implemented faster than in manufacturing, start measuring the former and begin solving problems.

Given the quality cost priority and available resources, initial FPY efforts concentrated on measuring quality in Order Management and Engineering. A defect in this process usually results in revising the details of an existing order or engineering drawing. Whether formal revision is mistake-driven or customer-driven, there is usually a negative impact to the production schedule. Examples of this impact include work flow being interrupted to seek clarification or await further instructions, materials needing to be reworked or scrapped or engineering spending valuable time coordinating the re-distribution of updated drawings. Even if a customer is charged for development, direct labor and material costs, the rework could introduce delays that affect other orders already in the production pipeline. Based on these ideas, the proposed FPY metric for Order Management and Engineering reflect the relationship between number of new orders (or designs) and the number of revisions:

$$\text{Order Mgmt. or Engineering FPY} = \left[1 - \left(\frac{\#\,\text{Revisions}}{\#\,\text{Revisions} + \#\,\text{New Orders}}\right)\right] * 100\%$$

This equation is NOT technically a yield, but the intent of the metric is to proportionally decrease the number of revisions (defects) in relation to new orders. Reducing the number of revisions to zero would indicate a defect-free process from the perspective of downstream operations.

The calculation of this metric was automated for each group. Order Management's software already enabled the tracking of revisions. Using Engineering's "Paperless Office" project, an algorithm was written that searches the existing file system and records the number of new designs and revisions created during a specified time period. To simplify metric generation for each group, a consolidated Microsoft ® Access tool was used to create a common, simple interface to generate the separate monthly reports. A description of the calculation form and an example report can be found in Appendix D.

As shown in Appendix D, the Engineering form includes a "Sum of Errors" field. This functionality tracks naming discrepancies within each order folder. An error is recorded whenever a file is found without a revision number or the file does not reference the correct order number. These documents do not get included in the FPY calculation, but error tracking helps measure the quality of the "Paperless Office" process. A list of error filenames is generated and allows the engineering group to correct file names that may have mistakes.

At the end of each month, each group lead opens the tool and generates a report. This report displays their respective FPY metric and presents a list of order numbers sorted by number of revisions. The purpose of this report is not to compare the relative performance of each organization because revisions in each group are usually not mutually exclusive. For example, a single revision by Order Management may prompt the revision of 10 drawings in Engineering, which would then count as 10 revisions for Engineering. The most important aspect of this list is that it provides a discussion context for each group to come together and ask why certain orders have a high number of revisions and what changes can be made to improve their internal processes. This metric also has visibility by the factory manager who keeps the groups accountable for measured improvement.

In keeping with the corporate Quality Manager's advice, the design of an automated tool facilitates metric calculation and allows each group to retain ownership of their FPY metric without a significant commitment of resources. Although the Engineering algorithm is somewhat complex, the algorithm's description, assumptions and risks were formally documented and communicated to key stakeholders in the company. If the code needs to be modified to more accurately reflect the impact of revisions, or if the "Paperless Office" process changes, then the factory has the capability and knowledge to accommodate revisions to the calculation methodology.

4.5 FPY Results and Future Work

Prior to internship completion, Order Management and Engineering were introduced to the calculation process and provided three months of back-calculated data. The tool was well received and the metric is currently being used as a talking point in the factory's monthly management meeting.

To generate a complete metric for the rest of the factory, FPY needs to be calculated for incoming goods (to track supplier defects) and production processes. The factory will have this calculation capability upon full implementation of the Quality Management System described in Chapter 3. In the meantime, the factory already tracks "Final Test" and "On-Time Delivery" metrics which give indication as to the health of their production processes. FPY should be used in conjunction with these metrics to give management a comprehensive view of their key business processes.

CHAPTER 5 - HIGH VOLTAGE WINDING STANDARDIZATION

5.1 Introduction

This chapter describes the development of a standardized production manual intended to reduce manufacturing variability in the HV Winding Shop, communicate best winding practices and integrate methods for Partial Discharge prevention. The reduction of failures in the HV Winding area will help reduce quality costs associated with "Operations Rework and Repair."

5.2 Problem Description

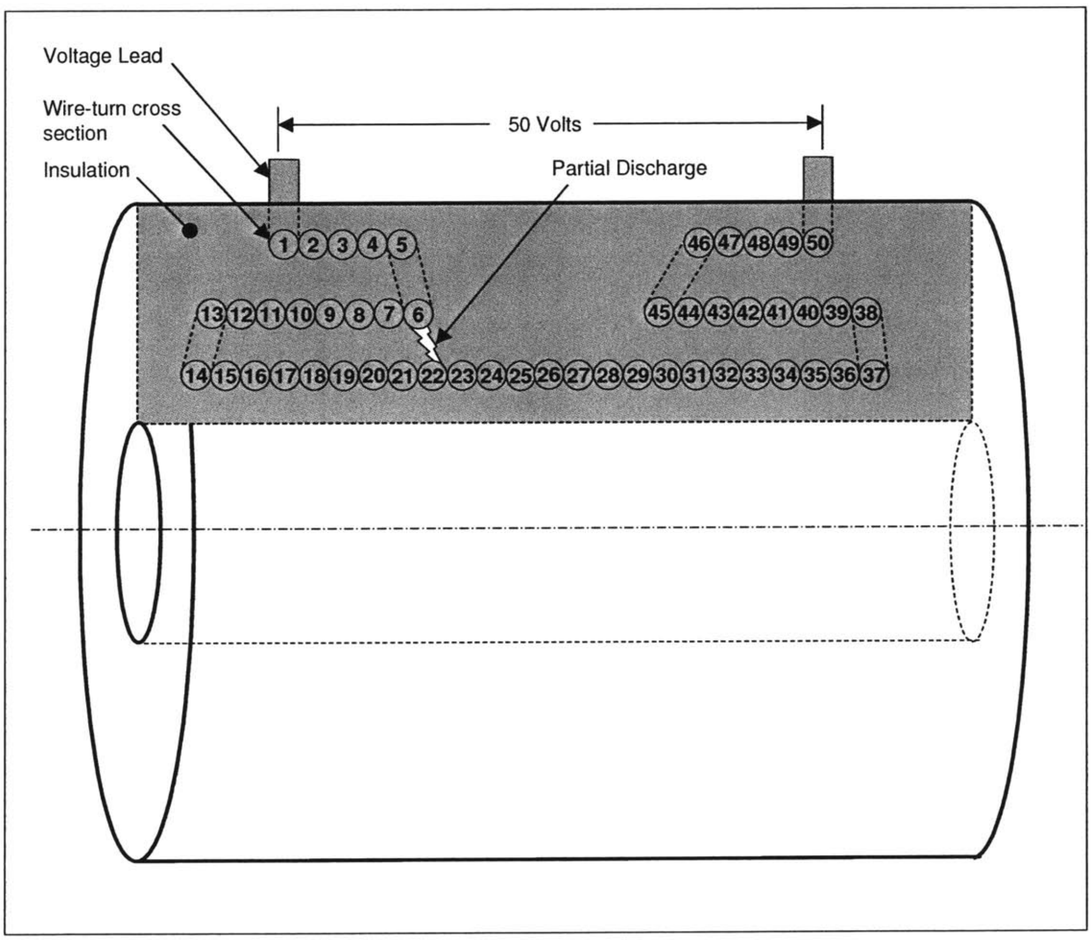
Rework attributed to High Voltage (HV) Winding represents a significant component of quality costs. HV Winding failures can also include other winding-related failures such as an incorrect number of conductor turns. However, as shown in the root cause analysis in Chapter 2, the majority of these costs come from Partial Discharge (PD) failures. Bharat (2005) defines PD as a "localized electrical discharge in insulating media which only partially bridges the insulation between conductors." There are strict IEC requirements governing the magnitude of such a discharge within a transformer. PD can occur between conductor layers, surrounding coil structure or in any area where high voltage stresses can be found. A detailed study of potential root causes will be addressed later in this chapter. However, the following represents a few circumstances that can initiate partial discharges in Dry-Type transformers (Bharat, 2005):

- Insufficient insulation or voids in the insulating material
- Overstressed insulation due to underestimating material voltage limitations
- High stress areas in conducting parts, which can be caused by sharp edges on the conductor or ground plane
- Contamination in the insulating material, such as metallic particles.

These factors can cause ionization within cavities embedded in the dielectric or along the surfaces of the winding. Although involving small amounts of energy, partial discharges may deteriorate the dielectric properties of insulating materials and dramatically impact transformer performance and/or safety.

In a simplified example, Figure 5.1 represents a cross section of a three-layer HV winding with a round wire as conductor material. Assuming the voltage potential between the main leads (wire numbers 1 and 50) is 50 Volts, the incremental voltage potential between adjacent turns would be 1 Volt. Therefore, the voltage potential between wires 6 and 22 is 16 Volts. If the insulation is not sufficient between these turns to bear the associated voltage stress, then a PD will occur as shown. Relatively more insulation is required between wires 6 and 45, where the voltage potential is 39 V.

Figure 5.1 Cross Section of High Voltage Winding



5.3 Challenges in HV Winding Standardization

Fabrik5's transformers are a mature product and the site has already spent much time trying to reduce the occurrence of quality failures such as PD. When a coil fails, engineers will often cut and evaluate a coil cross-section looking for suspicious indicators such as inadequate conductor clearances or voids in the material. Also, R&D has run countless statistical analyses trying to find PD correlations with factors such as transformer design configuration, voltage, and conductor size. However, PD failures appear frustratingly random.

Instead of approaching the problem from a design perspective, a process-based approach was applied looking at potential failure modes in production, namely the High Voltage Winding Shop. There were several challenges in addressing quality issues such as PD in this area:

- **Product Variability:** As previously mentioned, transformer coils would vary in size, configuration and conductor dimension. Some configurations can only be fabricated at certain winding stations.
- **Process Variability**: There were several HV Winding stations, each with a slightly different configuration and level of automation. There were also three shifts of workers (one worker per station). It was observed that many workers used different techniques depending on machine type, transformer design and personal style. A transformer coil that spans multiple shifts could be made using different winding methodologies.
- **Product Appraisal and Root Cause Analysis**: Although a few specific measurements such as coil diameter and conductor clearance are recorded during the actual winding process, many failure characteristics would not be discovered until Final Test. Therefore, a "bad" coil could consume valuable Finishing, Assembly, and Final Test resources until the failure is discovered. For failures such as PD, most of the 'evidence' is encased in a hard epoxy structure. There are currently four general methods to non-destructively locate a PD in large transformers (Bharat, 2005):

- Acoustic or visual detection methods use microphones or a dark room to locate corona discharges in air. However, neither method is effective if the PD is internal to the structure.
- Electrical location methods can typically isolate a problem coil using differential capacitance measurements, but this will not yield the point location of the failure.
- Ultrasonic methods use transducers to triangulate the location of a failure by measuring the time delay of pressure waves generated by a PD. The accuracy of this method in Dry-Type transformers is not sufficient to yield a point location.

- **Documentation:** Approximately 30 different documents were found outlining requirements for the HV Winding process. These documents ranged from high-level production manuals and formal technical memos to informal memos. The configuration management of this documentation was very complicated and often ignored.
- **Politics:** Past efforts to photograph and document winding processes have been met with some resistance by the local Union. These have been viewed as time studies with the goal of changing the agreed work standards.
- **Language:** The author's German language capabilities were limited and most of the floor workers did not speak English.

5.4 Root Cause Analysis

Partial Discharge is not a new problem for Powercomp or the transformer industry. However, the site had experienced a recent, unexplained increase in PD failures. While attending several brainstorming sessions involving R&D, Engineering and Production, a comprehensive list of potential root causes was compiled. By translating technical memos and employee interviews, ideas from past brainstorming sessions were also incorporated in the list.

The focus of the HV Winding research was based primarily on production methods. Along with statistical analysis, engineers had built analytical models in an attempt to predict the impact of certain design characteristics on local field strength, voltage stresses and dielectric capability. Becoming familiar with these efforts was important because they formed the basis for many production requirements. However, it was observed that production practices were not necessarily consistent with engineering requirements. Helping to realign production and engineering practices therefore became a major goal of this project.

In Stephen Spear's article, "Learning to Lead at Toyota," he emphasizes "there's no substitute for direct observation." He describes an American plant manager who spends several weeks in Japan working directly with line employees as a part of an intensive training program. Toyota's goal was to teach the manager how to observe manufacturing processes and rapidly test and implement improvements. Despite the significant language barrier, the manager and the workers were ultimately able to generate fast and measurable improvements.

Inspired by this philosophy, the author observed two or three HV workstations each week to become familiar with winding processes. Despite the language barrier, the workers grew accustomed to the author's presence. By drawing pictures, "asking" questions in broken German, and much pointing and grunting, relationships were slowly formed with winding employees from each shift. Roughly three weeks were spent taking notes, soliciting ideas from winding employees and recording opportunities for potential improvement, both in the areas of PD prevention and in productivity.

A cause-and-effect diagram was used to organize the list of potential PD causes from the brainstorming sessions while incorporating observations form the workshop floor. This diagram is also known as an Ishikawa or Fishbone Diagram and a detailed tool description can be found in most quality improvement guides. This tool was chosen because presenting the issues from each department on one diagram helped convey the extent of the PD problem to all factory parties. Appendix E shows a subset of the diagram generated from this exercise. Each branch was constructed using the "5-Whys" methodology, where each subsequent "why" narrows the scope of the problem to define a clear, rectifiable root cause (Shiba, 1993). The following steps provide an example of how a branch was created using this method:

- Why #1: "Why is there a failure?" The main problem statement at the right side of the diagram answers this question: **"transformer displays excessive partial discharge."** The failed requirement in Final Test initiates this process.
- *Why #2:* "Why did the transformer display excessive Partial Discharge?" The diagram branches off into five categories: Environment, Employee, Materials, Machine and Method. These categories can vary depending on the nature of the problem and analysis. Choosing the "Employee" category, the answer would be: "because there was an **Employee** error."
- *Why #3:* "Why was there an employee error?" Picking the first branch in this category, the answer would be: "because there was an error in the employee's **winding technique.**"
- *Why #4:* "Why was there an error in winding technique?" One branch answers: "because employees **develop non-standard techniques to solve unique problems**." For example, many of the larger conductors need to be clipped and filed prior to welding operations. Although the employees clean their respective areas after every shift, several opportunities were observed where the metal filings could come in contact with a transformer coil. If trapped inside the coil, these particulates could increase the probability of a PD failure.
- *Why #5:* "Why did the employee use this non-standard technique?" The final branch answers: because there was "**insufficient PD awareness**" on the shop floor. The employee was not aware of the contamination risk associated with the filing and clipping processes.

Many of the factors discussed during brainstorming events could not be shown in Appendix E due to confidentiality reasons. However, the factors displayed still reinforce the complexity of the PD problem. With so many opportunities for variation (many of which cannot be quantified), predicting or measuring the effectiveness of design improvements was a daunting task. Due to relatively long cycle times and high product variation, incorporating Design of Experiment (DOE) methods that modify and measure the effect of specific factor changes did not seem appropriate given the project duration. However, a few key insights were taken from this exercise:

- Winding technique significantly contributes to product uncertainty. Standardizing the process and communicating best practices will likely reduce the risk of PD.
- Production activities are not aligned with engineering standards. There was limited PD awareness among HV Winding employees, especially regarding the effect of hardware contamination.

The cause-and-effect diagram proved to be a tremendously persuasive tool to justify action in standardizing the HV Winding process. The results were presented to Engineering, Production and R&D management and their support quickly followed.

5.5 "PD *Oktoberfest*"

To align engineering intent with production practices, a quality brainstorming session was organized where representatives from Engineering, R&D, Production and several Winding personnel would spend one shift watching the winding of one coil. It was called the "PD *Oktoberfest*" and the goals were as follows:

- **To increase awareness of PD on the shop floor:** During the winding process, the team could point out failure opportunities and quickly brainstorm solutions.
- **To initiate a dialog between winding and management:** The winders needed to educate management on why certain techniques exist. Conversely, management needed to communicate the importance of specific requirements.
- **To initiate a dialog between winding teams:** Many of the specific winding techniques were purely stylistic while others were developed to accommodate differences in product or workstations. This event was an opportunity to share best practices.
- **To document a collection of best practices from the winding shop based on PD prevention and productivity:** Pictures and observations from this event could be used to create a more standardized process. The team would then have a baseline by which the factory could generate and measure improvements.

- To have fun and improve the relations between winding personnel and management: Labor relations had been strained due to production pressures and a recent increase in failures.

What does *Oktoberfest* have to do with Quality? *Oktoberfest* is an annual festival in Germany. It is a time of tremendous celebration, eating and beer drinking. Naming the event an *Oktoberfest* and incorporating some of its components generated a buzz around the factory and helped secure participation buy-in from winding personnel along with the local union. After the shift was completed, a small party was planned to celebrate the event involving catered food, traditional music (from MP3s) and of course beer.

An event of this nature had never been performed at this factory so planning, setting expectations and communication were critical to the workshop's success. There were several key considerations during the preparation process:

- **Management preparation:** A meeting was held with the management team to clarify the goals of the event and highlight process areas that needed special attention, such as the brazing process.
- **Worker preparation:** Prior to the event, a poster describing the PD problem and the event details was mounted in the winding area. Each of the winding participants was also given more specific descriptions of the event goals and expectations. Many workers were interested in participating and a full disclosure of event details and goals helped limit any perceived exclusivity.
- **Participation:** Management representation from R&D, Engineering, Production and Quality was critical to the event credibility. Also, the team had worker representation from each shift and each winding workstation to offer a breadth of experience and feedback. Well-respected winders were chosen who would be able to clarify the event details and results to the rest of the non-participating populace (half of the winders selected were team leaders for their respective shifts).
- **Configuration:** Coordinating with supply management, a design was chosen based on a recent wave of PD failures. It was understood that techniques applied

to this design may not apply to all transformer configurations, but having representation from other workstations would help clarify the differences and brainstorm common solutions.

- **Party preparation**: It was impossible to name something *Oktoberfest* without having a party. After the shift was completed, a small celebration was held in the company cafeteria with a catered lunch and a few beers. This also helped bridge the gap between management and winding employees and facilitate a more sustainable dialogue between functions. One of winding employees added a beer picture to the PD *Oktoberfest* description poster, further justifying the need for a party.

The Event was scheduled for 6:30am – 2:30 pm on a Saturday to minimize its impact on the rest of the factory. A senior employee was chosen as the main winder and the group watched as he performed each step of the winding process. Most of the event was conducted in German. However, a list of focus process areas and questions was given to the management team based on the cause-and-effect diagram observations. The author asked questions when appropriate.

Despite starting early in the morning, within the first 15 minutes the team found a contamination problem emanating from metallic guide channels used on most of the newer designs. The company had recently switched suppliers and the parts had thousands of small metallic burrs that easily broke off into coil hardware. This discovery was an extremely positive start. Throughout the day, the team generated a sizable list of process and design suggestions and there was a lively dialogue. Over 150 pictures were taken.

In the following weeks, a poster of the *Oktoberfest* results and associated actions was posted in the HV Winding area. In terms of quality costs, the workshop at a minimum discovered the contamination problem involving the metallic support rails. This was a likely explanation for the recent increase in PD failures. The coil manufactured during the event was an actual customer coil so the marginal cost for holding the event consisted primarily of labor and food. This expenditure was below the average cost to resolve two typical PD failures so there is no question it will have a significant positive return.

5.6 High Voltage Production Manual

When questions were asked during the *Oktoberfest,* several winders referenced a stack of production documents kept in a 3-ring binder at each station. As previously mentioned, approximately 30 different documents were found outlining many of the requirements for the HV Winding process. These included high-level production manuals (primarily for old-configurations), formal technical memos, and pieces of paper with only a date and several lines of instruction. Much of the documentation was outdated.

Using data from the PD *Oktoberfest* along with existing documentation and other brainstorming activities, a consolidated bi-lingual production manual was co-written by the author and R&D for distribution to the entire HV winding workshop. The 60-page manual included instructions for each general process step accompanied by pictures or drawings. It also included tips for PD prevention and highlighted examples of common bad practices that were no longer permitted. Although formally a production document, joint ownership was given to R&D. Therefore, as process changes are incorporated, the document must be formally reviewed by each group. Having only one document to update facilitates configuration management and gives the workers a common reference to suggest future process improvements. The development of this document was an iterative process. Prior to completion of the seven-month study, a first draft had been submitted to all PD *Oktoberfest* participants for feedback. Once the feedback was incorporated, it was recommended that all of HV winding employees would be formally trained in the new production practices.

There was no independent quality inspection in HV Winding so the workers were expected to inspect their own work. This presents a risk to this project because workers may continue their existing production practices despite information documented in the production manual. Therefore, maintaining an ongoing dialogue between management and HV Winders is critical to the long term success of the project. In the document, workers are encouraged to challenge the stated practices as long as they provide that feedback to R&D and production management.

5.7 Summary

The cause-and-effect diagram developed was not exhaustive. However, it tried to focus on the perceived dominant root causes while also incorporating several abstract ideas generated during group brainstorming. This was a useful tool in communicating the need for standardization in High Voltage Winding area. The wide range of potential root-causes reflected the complexity of the PD problem, but incorporating the "5-whys" methodology enabled managers to deconstruct these larger issues into more actionable problem statements. Armed with this data, management approval to hold the quality workshop was not difficult to attain.

In much of the Six-Sigma and Lean literature, Japanese words such as *kaisen* and *kanban* are often adopted into the culture of the company performing a related initiative. This common terminology helps give consistency to the volumes of available literature and facilitates the communication of best practices within or between companies. The PD *Oktoberfest* was essentially a *kaisen*-style event to demonstrate the benefits of continuous improvement. However, it incorporated an exciting part of the German culture. In the factory, people would smile whenever the *Oktoberfest* was mentioned. Given the local culture, this nomenclature was an effective method in facilitating buy-in for the continuous improvement problem solving methodology.

CHAPTER 6 - CONCLUSIONS

Given the transformer product's market, maturity, and current cost challenges, quality is a key strategic focus for the Fabrik5's long term survival as a profit center. This project's core benefit was helping the factory to understand the global responsibility for quality improvement and provided tools to facilitate this goal. Shiba (1993) describes this cross functional responsibility and collaboration as "total participation," where all employees contribute to the quality improvement efforts. This is especially important at Fabrik5, where the most of the factory personnel are expected to verify and inspect their own work. Increasing personnel's awareness of prevalent failure modes while also improving the communication link with technical management are critical steps to improving product quality.

6.1 Analysis Technique

The Cost of Quality framework incorporating prevention, appraisal, internal failure and external failure cost categories was useful in diagnosing key problem areas. It provided a more balanced view of the quality program when compared to the exclusive measurement failure costs. A notable insight came in quantifying appraisal costs. Although the internal failure cost category was chosen to be the immediate focus, it was observed that final test was the bottleneck process for several transformer configurations. Future investments in capacity, more advanced equipment or process improvements could yield significant long-term benefits, both in cost and lead-time reduction.

The model framework was chosen for consistency with existing company initiatives and it is not known whether another model would have yielded different project recommendations. Quantifying the overall impact of the quality program provided the necessary justification to pursue projects that were ultimately deemed valuable by factory management. Juran (1989) warns that companies can become bogged down in their cost of quality analyses, arguing about classifications and calling for a level of accuracy not needed for managerial decision making. The purpose of quality analysis is to diagnose and solve problems. Given the limited study duration, sufficient information was available to initiate meaningful projects. As the factory develops more sophisticated quality techniques, such as the implementation of formal Supplier Reviews, cost elements found in Appendix B not used in the initial study may become increasingly important.

For longer term improvements, Fabrik5 could benefit from a better understanding of the impact of customer dissatisfaction and lost sales. Because the factory gets most of its sales through a corporate intermediary, there is one degree of separation from the final customer, making it difficult to assess the market's perception of product quality. Having a clear view of customer needs from the perspective of delivery time, quality expectations, and price elasticity will enable the factory to better align quality expenditures with its competitive strategy.

6.2 Project Implementations

The initial quality cost exercise yielded three focus areas:

- Improve the documentation of failures with the goals of establishing more clarity in failure analysis and better management of corrective action projects.
- Establish a framework to monitor the Order Management and Engineering groups to help identify process quality issues and reduce the number of document revisions in each organization.
- Reduce rework due to operational issues in the High Voltage Winding department.

Quality Management System:

In response to the difficulty in understanding the root cause of many past failures, the factory's failure resolution process was redesigned. Based on Powercomp best practices and ISO 9001 requirements, a bi-lingual computer application was written to facilitate the compliant documentation and tracking of the site's quality failures. This tool distributes the responsibility for failure documentation and resolution from the Quality Manager to all functions in the organization. A "beta" version of the application was in user testing prior to study completion. For other Powercomp factories with similar strategic goals, this documentation tool could be easily transferred and customized to support local processes.

Sun et al. (2004) addresses some of the challenges European companies have had with ISO 9000 and TQM implementations, including perceived tensions between the two standards. For example, ISO 9000 is thought to be more rigid, focusing on defined processes and documentation while TQM encourages flexibility to support continuous improvement efforts throughout the organization. In the case of Fabrik5, the development of compliant documentation processes outlined in the QMS supports the continuous improvement ideals of TQM. The computerized application allows anyone with access to a computer to provide input to the problem description and resolution efforts, thus expanding the scope of quality responsibility in the organization. The approval process integrated with the QMS is in place to ensure adequate documentation is available to support future continuous improvement efforts and to facilitate the project management of these action items given the factory's limited resources. As the factory becomes more familiar with the QMS tool and trend capabilities are refined, the optimal level of detail required in the problem description, disposition and corrective action will be at the discretion of the new Quality Manager. However, the necessary fields are available in the tool and having electronic signature accountability will facilitate compliant documentation practices.

Design Changes:

Continuing the work from internal consultants, the management team began the implementation of a First Pass Yield (FPY) metric to give the factory a comprehensive measurement for quality performance in each major process area. An FPY tool was developed for the Order Management and Engineering departments based on the number of design revisions imposed after the start of production. This tool provides a structured framework from which both organizations can brainstorm process improvements and measure their success. The metric for other factory organizations will be available upon completion of the QMS tool.

The initial tool was received well by Order Management and Engineering, and the automated report generation makes it easier for the groups to view which orders have the highest number of revisions. FPY will be useful in establishing a comprehensive metric for factory health, but it should be used in conjunction with other key metrics such as On-Time delivery. Its greatest value will be in generating discussion with the ultimate goal of solving problems. As calculations for Incoming Goods and Manufacturing Processes are incorporated into the overall factory metric, management should re-evaluate the calculation methodologies for each process step to make sure the metric continues to provide useful insights into the factory's quality challenges.

Partial Discharge Failure and High Voltage Winding

After several weeks of direct observation and the famous "PD *Oktoberfest*", a bilingual production manual was compiled for the High Voltage Winding Shop based on internal best practices and PD prevention. The first revision consolidated over 30 separate production documents describing HV Winding and was submitted to the workshop floor for feedback prior to completion of this study.

As shown in the cause-and-effect diagram found in Appendix E, Partial Discharge failure may not be related to any one failure mode, but potentially the combination of modes. The factory can use this tool along with future quality cost analyses to determine the next round of quality improvement projects.

The "PD *Oktoberfest*" was a successful mechanism in facilitating collaborative problem solving between floor personnel and factory management. The factory is encouraged to hold future *Oktoberfests* to address revisions to the HV winding process. This method could also be utilized in other process areas to diagnose and support future quality or waste reduction initiatives.

As previously mentioned, the effectiveness of each of the aforementioned projects is ultimately dependent on the new Quality Manager. The factory has limited resources and despite attempts to build the improvements into automated tools and provide documentation to facilitate a smoother management transition, the projects will fade if there is no formal project champion. This reflects the tradeoff between taking one project through a complete implementation versus multiple projects through partial implementations. The latter approach was chosen because it was believed sufficient progress could be made on each to demonstrate benefits and thus convince the site of the project's long term value. By continuing these initiatives, Fabrik5 has a tremendous opportunity to decrease failure costs, reduce waste and ultimately increase the profitability and competitive position of their transformer product.

APPENDIX A: ABBREVIATIONS

BOM = Bill of Materials
CoQ = Cost of Quality
CoPQ = Cost of Poor Quality
DOE = Design of Experiments
FPY = First Pass Yield
HV = High Voltage
IEC = International Electrotechnical Commission
ISO = International Organization for Standardization
LV = Low Voltage
NCR = Non-Conformance Report
PD = Partial Discharge
PO = Purchase Order
QMS = Quality Management System
TFO = Transformer

APPENDIX B: QUALITY COST ELEMENTS

Note on the Model: Most of the elements listed below are verbatim copies of those found in Campanella's *Principles of Quality Costs* (PoQC) and are listed here for quick reference. There are several elements in Appendix B that were not included in the initial analysis. This indicates that the monetary value was either already summed into another measurement or the exercise was not yet performed in the factory. These elements were left in the model as a reference if the factory chooses to further develop their quality costing techniques in search of future returns. For example, if production invests in formal 'Quality Education' for operators, this cost would need to be accounted for as a Prevention Cost. Also, a 'Supplier Rating' system may prove useful as the factory expands its supply base in search of lower cost or more flexible suppliers.

PoQC Ref	Quality Cost Element	Definition	Included (Yes/No)	Accuracy		
				High	Mod	Less
1.0	Prevention Costs	The costs of all activities specifically designed to prevent poor quality in products or services.	Yes			
1.1	Marketing/ Customer/User	Costs incurred in the accumulation and continued evaluation of customer and user quality needs and perceptions (including feedback on reliability and performance) affecting their satisfaction with the company's product or service. This includes: 1. The cost of that portion of marketing research devoted to the determination of customer and user quality needs-attributes of the product or service that provide a high degree of satisfaction. 2. The cost of programs designed to communicate with customers/users for the expressed purpose of determining their perception of product or service quality as delivered and used, from the viewpoint of their expectations and needs relative to competitive offerings. 3. Costs incurred in the review and evaluation of customer contracts or other documents affecting actual product or service requirements (such as applicable industry standards, government regulations, or customer internal specifications) to determine the company's capability to meet the stated requirements, prior to acceptance of the customer's terms	Yes			1
1.2	Product/Service/ Design Development	Costs incurred to translate customer and user needs into reliable quality standards and requirements and to manage the quality of new product or service developments prior to the release of authorized documentation for initial production. These costs are normally planned and budgeted and are applied to major design changes as well.	No			

PoQC Ref	Quality Cost Element	Definition	Included (Yes/No)	Accuracy		
				High	Mod	Less
1.2.1	Design Quality Progress Reviews	The total cost, including planning, of interim and final design progress reviews, conducted to maximize conformance of product or service design to customer or user needs with regard to function, configuration, reliability, safety, producability, unit cost, and, as applicable, serviceability, interchangeability, and maintainability. These formal reviews will occur prior to release of design documents for fabrication of prototype units or start of trial production.	No			
1.2.2	Design Support Activities	The total cost of all activities specifically required to provide tangible quality support inputs to the product or service development effort. As applicable, design support activities include design document checking to assure conformance to internal design standards; selection and design qualification of components and/or materials required as an integral part of the end-product or service; risk analyses for the safe use of end-product or service; produceability studies to assure economic production capability; maintainability or serviceability analyses; reliability assurance activities, such as failure mode and effects analysis and reliability apportionment; analysis of customer misuse and abuse potential; and preparation of an overall quality management plan.	Yes			1
1.2.3	Product Design Qualification Test	Costs incurred in the planning and conduct of the qualification testing of new products and major changes to existing products includes costs for the inspection and test of a sufficient quantity of qualification units under ambient conditions and the extremes of environmental parameters (worst case conditions). Qualification inspections and tests are conducted to verify that all product design requirements have been met or, when failures occur, to clearly identify where redesign efforts are required. Qualification testing is performed on prototype units, pilot runs, or a sample of the initial production run of new products. (Some sources consider this an appraisal cost.)	Yes		1	
1.3	**Purchasing Prevention Costs**	**Costs incurred to assure conformance to requirements of supplier parts, materials, or processes and to minimize the impact of supplier nonconformances on the quality of delivered products or services. Involves activities prior to and after finalization of purchase order commitments**	**Yes**			1
1.3.1	Supplier Reviews	The total cost of surveys to review and evaluate individual suppliers' capabilities to meet company quality requirements. Usually conducted by a team of qualified company representatives from affected departments. Can be conducted periodically for long-term associations.	No			
1.3.2	Supplier Rating	The cost of developing and maintaining, as applicable, a system to ascertain each supplier's continued acceptability for future business. This rating system is based on actual supplier performance to established requirements, is periodically analyzed, and is given a quantitative or qualitative rating.	No			
1.3.3	Purchase Order Tech Data Reviews	The cost for reviews of purchase order technical data (usually by other than purchasing personnel) to assure its ability to clearly and completely communicate accurate technical and quality requirements to suppliers.	No			

PoQC Ref	Quality Cost Element	Definition	Included (Yes/No)	Accuracy High	Mod	Less
1.3.4	Suppler Quality Planning	The total cost of planning for the incoming and source inspections and tests necessary to determine acceptance of supplier products. Includes the preparation of necessary documents and development costs for newly required inspection and test equipment.	No			
1.4	**Operations (Manufacturing or Service) Prevention Costs**	**Costs incurred in assuring the capability and readiness of operations to meet quality standards and requirements; quality control planning for all production activities; and the quality education of operating personnel.**	**Yes**			1
1.4.1	Operations Process Validation	The cost of activities established for the purpose of assuring the capability of new production methods, processes, equipment, machinery, and tools to initially and consistently perform within required limits.	No			
1.4.2	Operations Quality Planning	The total cost for development of necessary product or service inspection, test, and audit procedures; appraisal documentation system; and workmanship or appearance standards to assure the continued achievement of acceptable quality results. Also includes total design and development costs for new or special measurement and control techniques, gages, and equipment.	Yes			1
1.4.3	Operations Support Quality Planning	The total cost of quality control planning for all activities required to provide tangible quality support to the production process. As applicable, these production support activities include, but are not limited to, preparation of specifications and the construction or purchase of new production equipment; preparation of operator instructions; scheduling and control plans for production supplies; laboratory analysis support; data processing support; and clerical support.	No			
1.4.4	Operator Quality Education	Costs incurred in the development and conduct of formal operator training programs for the expressed purpose of preventing errors-programs that emphasize the value of quality and the role that each operator plays in its achievement. This includes operator training programs in such subjects as statistical quality control, process control, quality circles, and problem-solving techniques. This item is not intended to include any portion of basic apprentice or skill training necessary to be qualified for an individual assignment within a company.	No			
1.5	**Quality Administration**	**Costs incurred in the overall administration of the quality management function.**	**Yes**	1		
1.5.1	Administrative Salaries	Compensation costs for all quality function personnel (such as managers and directors, supervisors, and clerical) whose duties are 100 percent administrative.	Yes	1		
1.5.2	Administrative Expenses	All other costs and expenses charged to or allocated to the quality management function not specifically covered elsewhere in this system (such as heat, light, and telephone).	Yes	1		

PoQC Ref	Quality Cost Element	Definition	Included (Yes/No)	Accuracy High	Mod	Less
1.5.3	Quality Program Planning	The cost of quality (procedure) manual development and maintenance, inputs to proposals, quality recordkeeping, strategic planning, and budget control.	No			
1.5.4	Quality Performance Reporting	Costs incurred in quality performance data collection, compilation, analysis, and issuance in report forms designed to promote the continued improvement of quality performance. Quality cost reporting would be included in this category.	Yes			1
1.5.5	Quality Education	Costs incurred in the initial (new employee indoctrination) and continued quality education of all company functions that can affect the quality of product or service as delivered to customers. Quality education programs emphasize the value of quality performance and the role that each function plays in its achievement.	No			
1.5.6	Quality Improvement	Costs incurred in the development and conduct of companywide quality improvement programs, designed to promote awareness of improvement opportunities and to provide unique individual opportunities for participation and contributions.	No			
1.5.7	Quality System Audits	The cost of audits performed to observe and evaluate the overall effectiveness of the quality management system and procedures. Often accomplished by a team of management personnel. Auditing of product is an appraisal cost. (See 2.2. 1.)	No			
1.6	**Other Prevention Costs**	**Represents all other expenses of the quality system, not previously covered, specifically designed to prevent poor Quality of product or service.**	**No**			
2.0	**Appraisal Costs**	**The costs associated with measuring, evaluating, or auditing products or services to assure conformance to quality standards and performance requirements.**	**Yes**			
2.1	**Purchasing Appraisal Costs**	**Purchasing appraisal costs generally can be considered as the costs incurred for the inspection and/or test of purchased supplies or services to determine acceptability for use. These activities can be performed as part of a receiving inspection function or as a source inspection at the supplier's facility.**	**Yes**			1
2.1.1	Receiving or Incoming Inspections and Tests	Total costs for all normal or routine inspection and/or test of purchased materials, products, and services. These costs represent the baseline costs of purchased goods appraisal as a continuing part of a normal receiving inspection function.	Yes			1
2.1.2	Measurement Equipment	The cost of acquisition (depreciation or expense costs), calibration, and maintenance of measurement equipment, instruments, and gages used for appraisal of purchased supplies.	No			

PoQC Ref	Quality Cost Element	Definition	Included (Yes/No)	Accuracy High	Mod	Less
2.1.3	Qualification of Supplier Product	The cost of additional inspections or tests (including environmental tests) periodically required to qualify the use of production quantities of purchased goods. These costs are usually one-time costs, but they may be repeated during multiyear production situations. The following are typical applications: a. First article inspection (detailed inspection and worst case tests) on a sample of the first production buy of new components, materials, or services b. First article inspection for second and third sources of previously qualified end-product key components c. First article inspection of the initial supply of customer-furnished parts or materials d. First article inspection of the initial purchased quantity of goods for resale	No			
2.1.4	Source Inspection and Control Programs	All company-incurred costs (including travel) for the conduct of any of the activities described in 2. 1. 1 and 2. 1.3 at the supplier's plant or at an independent test laboratory. This item will normally include all appraisal costs associated with direct shipments from supplier to the customer, sales office, or installation site.	No			
2.2	**Operations (Manufacturing or Service) Appraisal Costs**	**Operations appraisal costs generally can be considered as the costs incurred for the inspections, tests, or audits required to determine and assure the acceptability of a product or service to continue into each discrete step in the operations plan from start of production to delivery. En each case where material losses are an integral part of the appraisal operation, such as machine set-up pieces or destructive testing, the cost of the losses is to be included.**	**Yes**	1		
2.2.1	Planned Operator Inspections, Tests, Audits	The cost of all planned inspections, tests, and audits conducted on a product or service at selected points or work areas throughout the overall operations process, including the point of final product or service acceptance. Also includes the total cost of any destructive test samples required. This is the baseline operations appraisal cost. It does not include the cost of troubleshooting, rework, repair, or the sorting of rejected lots, all of which are defined as failure costs. This includes: 1. Work performed by individuals other than inspectors as in-process evaluation. Typically, part of a production operator's job. 2. Personnel expense as a result of performing quality audits on in-process or finished products or services. 3. Materials consumed or destroyed in control of quality, such as by tear-down inspections, over-voltage stressing, drop testing, or life testing.	Yes	1		
2.2.2	Set-Up Inspection and Tests	The cost of all set-up or first piece inspections and tests used to assure that each combination of machine and tool is properly adjusted to produce acceptable products before the start of each production lot or that service processing equipment (including acceptance and test devices) is acceptable for the start of a new day, shift, or other time period.	No			
2.2.3	Special Tests (Manufacturing)	The cost of all nonroutine inspections and tests conducted on manufactured product as a part of the appraisal plan. These costs normally include annual or semi-annual sampling of sensitive product for more detailed and extensive evaluations to assure continued conformance to critical environmental requirements.	No			

PoQC Ref	Quality Cost Element	Definition	Included (Yes/No)	Accuracy High	Mod	Less
2.2.4	Process Control Measurements	The cost of all planned measurements conducted on in-line product or service processing equipment and/or materials (such as oven temperature or material density) to assure conformance to pre-established standards. Includes adjustments made to maintain continued acceptable results.	Yes			1
2.2.5	Laboratory Support	The total cost of any laboratory tests required in support of product or service appraisal plans.	No			
2.2.6	Measurement (Inspection and Test) Equipment	Since any measurement or process control equipment required is an integral part of appraisal operations, its acquisition (depreciation or expense), calibration, and maintenance costs are all included. Control of this equipment assures the integrity of results, without which the effectiveness of the appraisal program would be in jeopardy.	Yes	1		
2.2.7	Outside Endorsements and Certifications	The total cost of required outside endorsements or certifications, such as Underwriter's Laboratory, ASTM, or an agency of the U.S. government. Includes the cost of sample preparation, submittal, and any liaison necessary to its final achievement. Includes cost of liaison with customers.	Yes	1		
2.3	**Review of Test and Inspection Data**	**Costs incurred for regularly reviewing inspection and test data prior to release of the product for shipment, such as determining whether product requirements have been met**	**Yes**			1
3.0	**Internal Failure Costs**	**Costs resulting from products or services not conforming to requirements or customer/user needs. Internal failure costs occur prior to delivery or shipment of the product, or the furnishing of a service, to the customer.**	**Yes**			
3.1	**Product/Service Design Failure Costs (Internal)**	**Design failure costs can generally be considered as the unplanned costs that are incurred because of inherent design inadequacies in released documentation for production operations. They do not include billable costs associated with customer-directed changes (product improvements) or major redesign efforts (product upgrading) that are part of a company-sponsored marketing plan.**	**Yes**			
3.1.1	Design Corrective Action	After initial release of design for production, the total cost of all problem investigation and redesign efforts (including re-qualification as necessary) required to completely resolve product or service problems inherent in the design. (Some sources consider this a prevention cost.)	No			
3.1.2	Rework Due to Design Changes	The cost of all rework (materials, labor, and applicable burden) specifically required as part of design problem resolutions and implementation plans (effectivity) for required design changes.	Yes		1	
3.1.3	Scrap Due to Design Changes	The cost of all scrap (materials, labor, and applicable burden) required as part of design problem resolutions and implementation plans (effectivity) for design changes.	No			
3.1.4	Production Liaison Costs	The cost of unplanned production support efforts required because of inadequate or incomplete design description and documentation by the design organization.	No			

PoQC Ref	Quality Cost Element	Definition	Included (Yes/No)	Accuracy High	Mod	Less
3.2	**Purchasing Failure Costs**	**Costs incurred due to purchased item rejects.**	**Yes**			
3.2.1	Purchased Material Reject Disposition Costs	The cost to dispose of, or sort, incoming inspection rejects. Includes the cost of reject documentation, review and evaluation, disposition orders, handling, and transportation (except as charged to the supplier).	No			
3.2.2	Purchased Material Replacement Costs	The added cost of replacement for all items rejected and returned to supplier. Includes additional transportation and expediting costs (when not paid for by the supplier).	No			
3.2.3	Supplier Corrective Action	The cost of company-sponsored failure analyses and investigations into the cause of supplier rejects to determine necessary (corrective actions. Includes the cost of visits to supplier plants for this purpose and the cost to provide necessary added inspection protection while the problem is being resolved. (Some sources consider this a prevention cost.)	No			
3.2.4	Rework of Supplier Rejects	The total cost of necessary supplier item repairs incurred by the company and not billable to the supplier-usually due to production expediencies.	Yes		1	
3.2.5	Uncontrolled Material Losses	The cost of material or parts shortages due to damage, theft, or other (unknown) reasons. A measure of these costs may be obtained from reviews of inventory adjustments.	No			
3.3	**Operations (Product or Service) Failure Costs**	**Operations failure costs almost always represent a significant portion of overall quality costs and can generally be viewed as the costs associated with defective product or service discovered during the operations process. They are categorized into three distinct areas: material review and corrective action, rework/repair costs, and scrap costs.**	**Yes**		1	
3.3.1	Material Review and Corrective Action Costs	Costs incurred in the review and disposition of nonconforming product or service and the corrective actions necessary to prevent recurrence.	Yes			1
3.3.2	Operations Rework and Repair costs	The total cost (labor, material, and overhead) of reworking or repairing a defective product or service discovered within the operations process. This includes: 1. The total cost (material, labor, and burden) of all work done to bring nonconforming product or service up to an acceptable (conforming) condition, as authorized by a specific work order, blueprint, personal assignment, or planned part of the standard operating process. Does not include rework due to design change (3.1.2). 2. The total cost (material, labor, and burden) of all work done to bring nonconforming product up to an acceptable or equivalent, but still nonconforming, condition; normally accomplished by subjecting the product to an approved process that will reduce but not completely eliminate the nonconformance.	Yes		1	

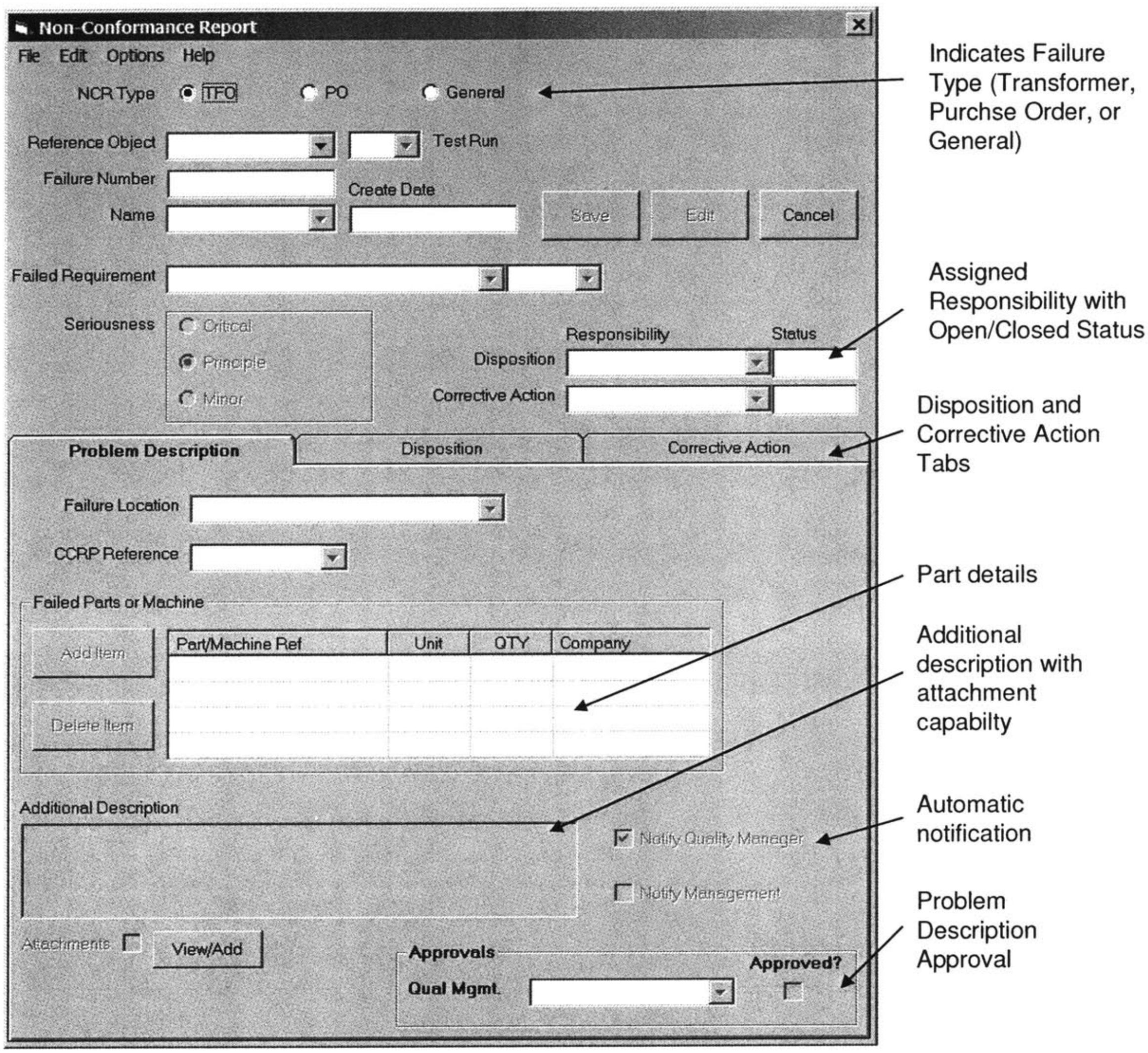
PoQC Ref	Quality Cost Element	Definition	Included (Yes/No)	Accuracy High	Mod	Less
3.3.3	Reinspection/Retest Costs	That portion of inspection, test, and audit labor that is incurred because of rejects (includes documentation of rejects, reinspection or test after rework/repair, and sorting of defective lots).	Yes			1
3.3.4	Extra Operations	The total cost of extra operations, such as touch-up or trimming, added because the basic operation is not able to achieve conformance to requirements. These costs are often hidden in the accepted (standard) cost of operations.	No			
3.3.5	Operations Scrap Costs	The total cost (material, labor, and overhead) of defective product or service that is wasted or disposed of because it cannot be reworked to conform to requirements. The unavoidable losses of material (such as the turnings from machining work or the residue in a food mixing pot) are generally known as waste (check company cost accounting definitions) and are not to be included in the cost of quality. Also, in the definition of quality costs, the amount received from the sale of scrap and waste material (salvage value) is not to be deducted from gross scrap failure costs.	No			
3.3.6	Downgraded End product or Service	Price differential between normal selling price and reduced selling price due to nonconforming or off-grade end-products or services because of quality reasons. Also includes any costs incurred to bring up to saleable condition.	No			
3.3.7	Internal Failure Labor Losses	When labor is lost because of nonconforming work, there may be no concurrent material losses, and it is not reflected on scrap or rework reports. Accounting for the cost of labor for such losses is the intent of this item. Typical losses occur because of equipment shutdowns and reset-up or line stoppages for quality reasons and may be efficiency losses or even allocated for by "labor allowances."	No			
3.4	**Other internal Failure costs**		**Yes**		1	
4.0	**External Failure Costs**	**Costs resulting from products or services not conforming to requirements or customer/user needs. External failure costs occur after delivery or shipment of the product, and during or after furnishing of a service, to the customer.**	**Yes**			
4.1	Complaint Investigations/Customer or User Service	The total cost of investigating, resolving, and responding en individual customer or user complaints or inquiries, including necessary field service.	Yes			1
4.2	Returned Goods	The total cost of evaluating and repairing or replacing goods not meeting acceptance by the customer or user due to quality problems. It does not include repairs accomplished as part of a maintenance or modification contract.	No			

PoQC Ref	Quality Cost Element	Definition	Included (Yes/No)	Accuracy High	Mod	Less
4.3	Retrofit Costs	Costs to modify or update products or field service facilities to a new design change 1evel, based on major redesign due to design deficiencies. Includes only that portion of retrofits that are due to quality problems.	No			
4.3.1	Recall Costs	Includes costs of recall activity due to quality problems.	No			
4.4	Warranty Claims	The total cost of claims paid to the customer or user, after acceptance, to cover expenses, including repair costs such as removing defective hardware From a system or cleaning costs due to a food or chemical service accident. In cases where a price reduction is negotiated in lieu of warranty, the value of this reduction should be counted.	Yes	1		
4.5	Liability Costs	Company-paid costs due to liability claims, including the cost of product of service liability insurance.	Yes	1		
4.6	Penalties	Cost of any penalties incurred because of less than full product or service performance achieved (as required by contracts with customers or by government rules and regulations).	No			
4.7	Customer/User Goodwill	Costs incurred, over and above normal selling cots, to customers or users who are not completely satisfied with the quality of a delivered product or service, such as costs incurred because of customers' quality expectations are greater than what they receive.	No			
4.8	Lost Sales	Includes value of contribution margin lost due to sales reduction because of quality problems.	No			
4.9	Other External Failure Costs.		No			

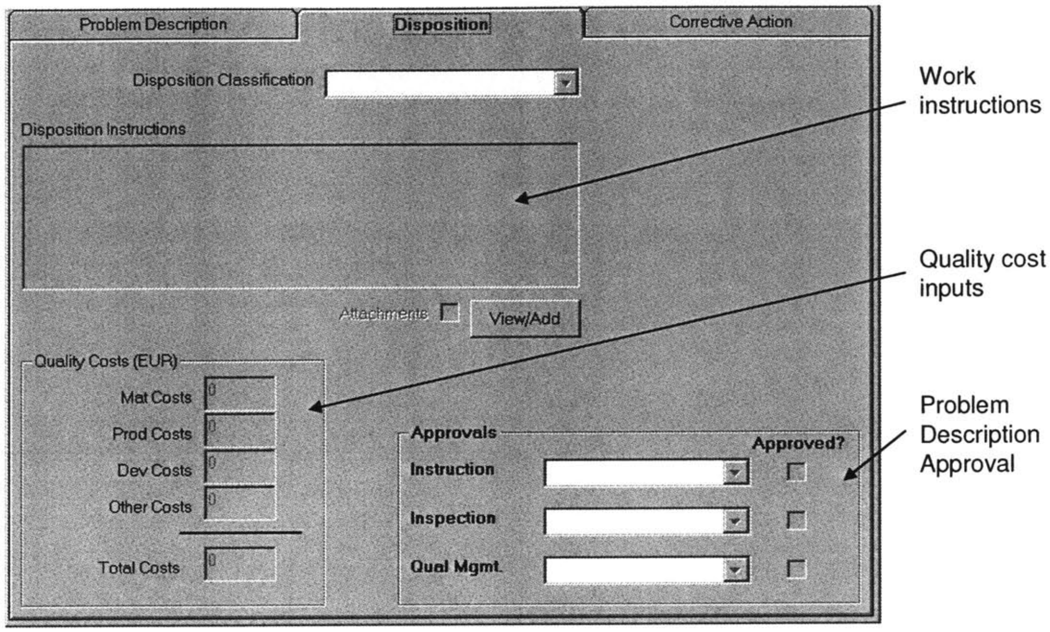
APPENDIX C: QUALITY MANAGEMENT SYSTEM (QMS) TOOL

This section describes the main failure documentation form for the QMS program. There are several other forms such as a Test Results screen, Attachment screen and Search screen now shown in this document. The English version is displayed, but the language can be toggled to German through the Options menu.

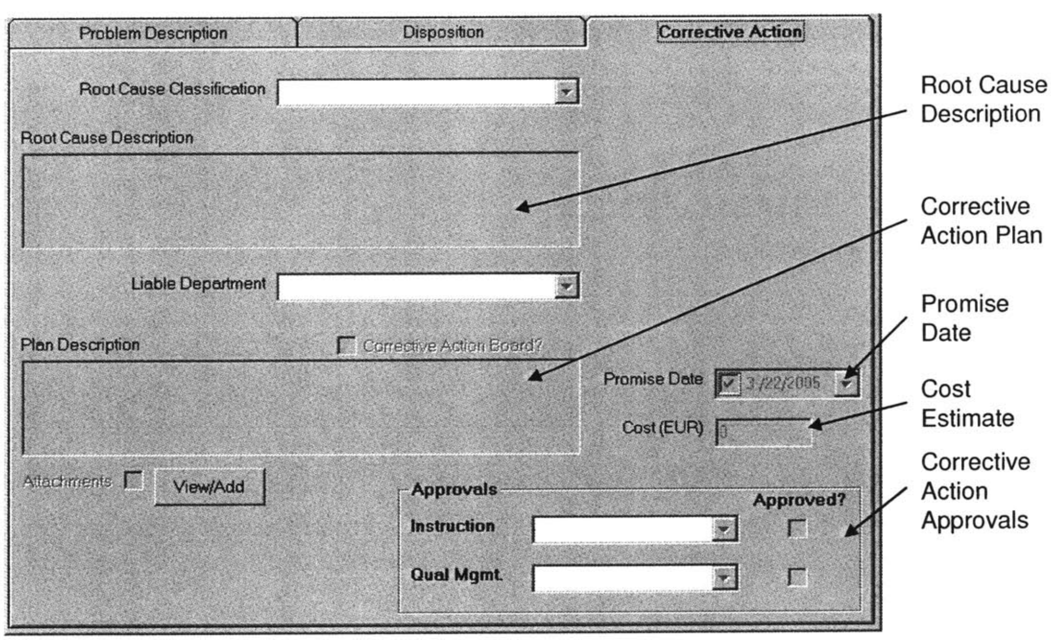
Problem Description Screen and Tab



Disposition Tab

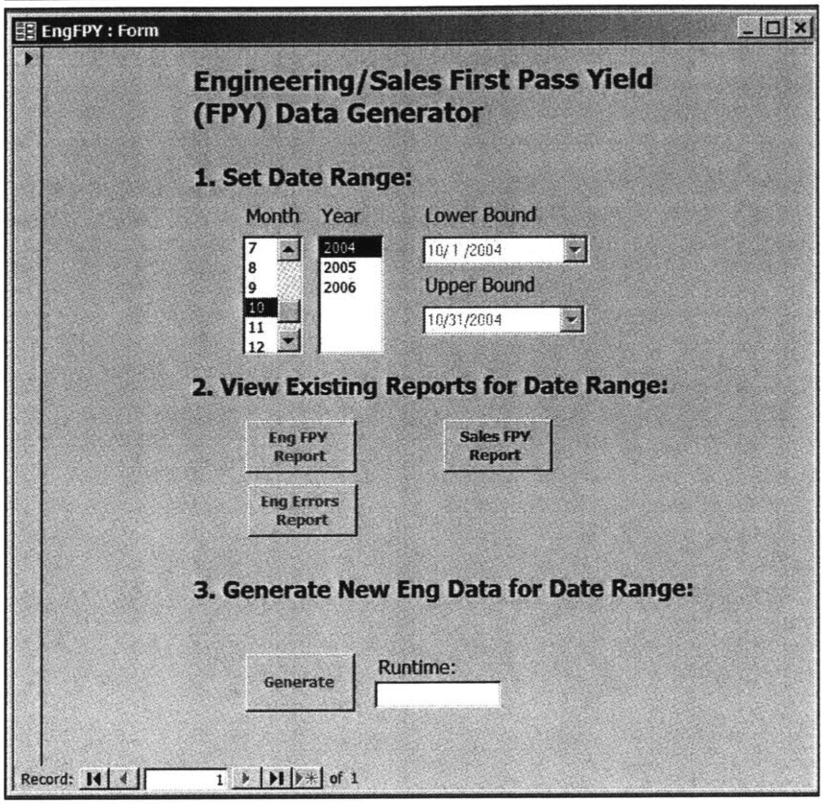


Corrective Action Tab



APPENDIX D: FIRST PASS YIELD (FPY) TOOL INTERFACE

Calculator Interface:



First Page of Sample Report:

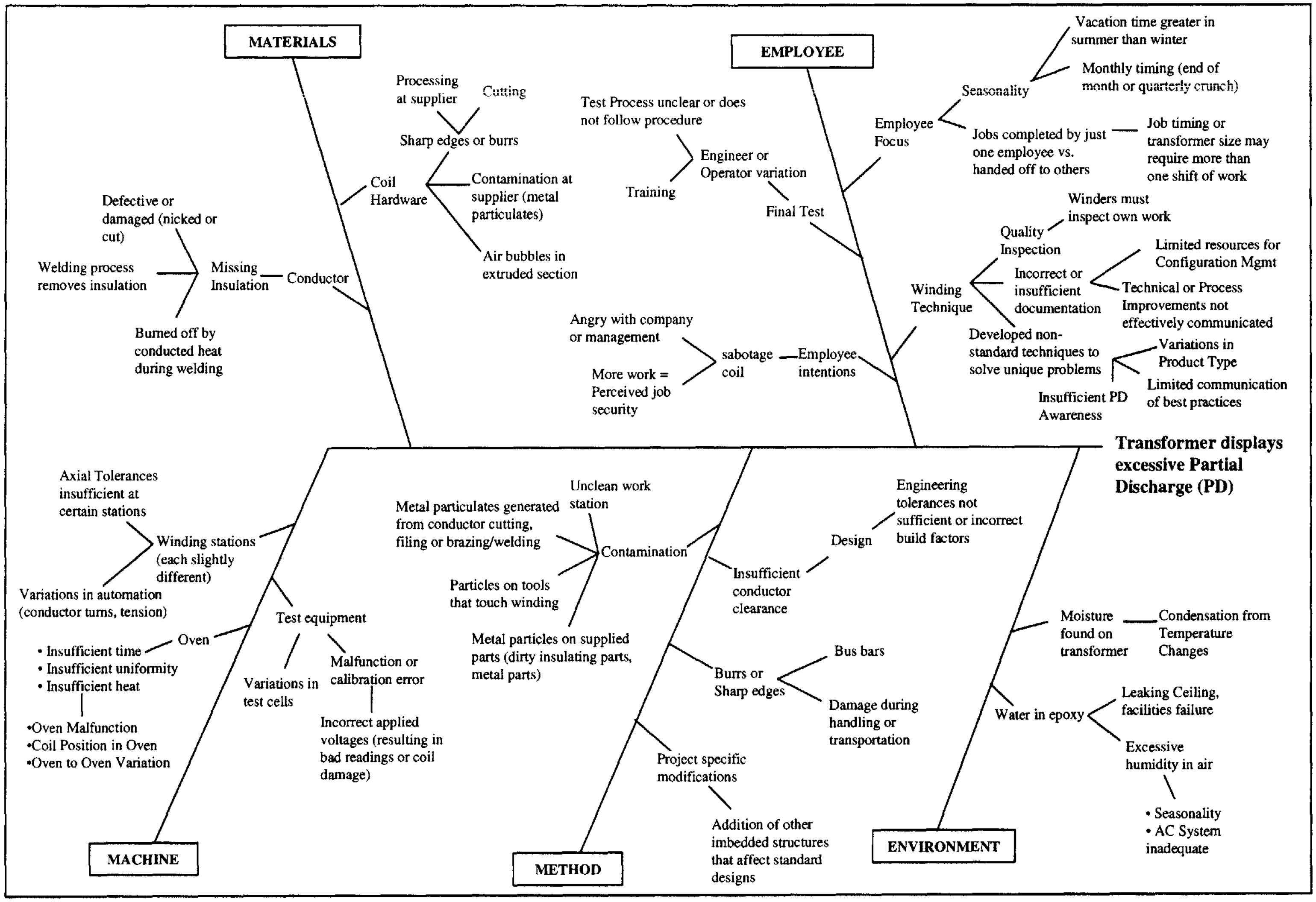
Engineering First Pass Yield (FPY)

Time Period: **10/2004**
Total New Designs: **210**
Total Revisions: **150**
Total Errors: **10**

$$EngFPY = 1 - \frac{\#\text{Revisions}}{\#\text{NewDesigns} + \#\text{Revisions}} = \mathbf{58.3\%}$$

OrderFld	*SumOfRevisions*	*SumOfNewDesign*	*SumOfErrors*
1411205	15	1	0
2411589	13	1	1
4414456	10	1	0
5434545	8	0	0
1325567	8	0	1

APPENDIX E: PARTIAL DISCHARGE CAUSE-AND-EFFECT DIAGRAM



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