Analysis of Investments in Process Control Tools: Laser Scanners used for On-Line Inspection in a Polyester Sheet Production Process

by
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ABSTRACT

In the late 1980s and through the 1990s, the importance of quality within American manufacturing companies has been elevated to increasingly higher levels. This has led to progressively more investments in quality improvement projects. While the results of the investments in quality appear to be very positive, the specific benefits can be difficult to quantify. Inability to estimate the positive cash flows from a quality improvement project leads to a lack of meaningful financial project analysis. Without financial analysis, there is a vacuum of information for the person making decisions regarding investments in quality improvement projects. This thesis examines the investment decision making process for quality improvement projects and applies the key learnings to the financial analysis of a specific project at the Eastman Kodak Company.

A project performed within the Roll Coating Division of Eastman Kodak is the basis for this thesis. The project consisted of first a comparative evaluation of two different laser scanner systems and then an investigation of the process for evaluating the investment in these laser scanners. Within a polyester sheet making operation, on-line laser scanners can be used for both product dispositioning and process control. Intec and Sira/Veredus laser scanners were evaluated and compared on performance and costs (maintenance & capital). A cost of quality framework was used to provide a comprehensive measurement of the benefits due to the laser scanners, and the value of investing in each scanner was measured through calculation of project Net Present Value (NPV) and Internal Rate of Return(IRR).

Following are the results of the comparative evaluation of laser scanners and examination of the investment decision making process:

1) The Intec is superior to the Sira/Veredus in terms of both performance and cost.
2) Conventional methods of financial analysis such as NPV and IRR are appropriate for analyzing quality improvement projects if a comprehensive framework is used to measure the benefits.
3) For the case of the laser scanners used in polyester sheet making, a cost of quality framework was found to be a very useful, comprehensive framework for broadly capturing and quantifying the benefits due to the investment.

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The basis for this thesis was my internship in the Roll Coating division at Kodak. My thanks go to all the people in Roll Coating and MR&E who welcomed me and generously provided assistance during my internship. Special thanks go to the product and process staff in ESTAR production.

Finally, my deepest appreciation to my parents and family for their unwavering support in all of my endeavors.

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1.0 Introduction

During the 1980s, American manufacturing companies faced increasingly stiff competition from foreign manufacturers both in terms of price and quality. Manufacturing in the United States has its roots in the mass production of standard goods and an extreme division of labor. High production volumes, standard product features, and division of tasks was the paradigm for the most efficient, low cost method of manufacturing. While many aspects of manufacturing in America have changed since its development in the early 1900's, the emphasis on efficiencies and costs without an equal regard for quality continued in many industries through the late 1970s. However, through their increasing purchases of goods from foreign manufacturers with reputations for high quality, the American consumer began to demand high quality products in the 1980s.

Consumer demands for quality led to a wave of companies implementing Total Quality programs and a focus on investing in quality in the 1980s. In some cases the pendulum swung too far the other way and investments in quality were pursued without careful consideration of the benefits that would be realized. At a number of companies, investments in quality were viewed as similar to safety and environmental projects in the aspect of requiring little financial justification for the investments. Two major factors contributed to a pattern of investing in quality without sufficient quantification of expected benefits.

1) The attitude that expenditures to improve quality did not need to be justified through financial metrics.
2) A view that the benefits of quality improvement projects could not be quantified.

As described in the cover story of the August 8, 1994 issue of BUSINESS WEEK entitled "Quality: How To Make It Pay," many companies have shifted their paradigm to the point where quality improvement projects must meet certain financial hurdles.[1] Given that the first factor has changed within many companies, the second factor of difficulty in quantifying the benefits of these investments can still be a problem. Lack of clarity in

[1] David Greising, "Quality: How To Make It Pay," BUSINESS WEEK, August 8, 1994, pp. 54-59.

identifying and quantifying the benefits of a quality improvement project can lead to the following two problems:

1) Incomplete information for making the project investment decision.
2) Lack of focus in achieving these benefits during project implementation and continuous improvement efforts.

This thesis examines the issues regarding the investment decision in an on-line quality inspection system and how to successfully implement the system to achieve the expected benefits.

1.1 Themes & Case Study

The thesis will focus on the following two themes and an analysis of a specific set of quality improvement investments in the Roll Coating Division of the Eastman Kodak Company.

1) Using a Cost of Quality (COQ) framework to identify and quantify the benefits of a quality improvement project.
2) The investment decision making process specific to capital investments in quality improvement projects.

The Roll Coating Division (RCD) has invested in two different types of laser scanner systems for on-line detection of defects in several polyester sheet production lines. In chapter two, the technology of laser scanners and their application in RCD will be investigated. In addition, the thesis will provide a comparative evaluation of the two scanners systems (chapter three) leading to a recommendation for future investments in laser scanners. A COQ framework will be used to identify and quantify the potential benefits from the laser scanners systems in chapter four . Chapter five will examine why a discounted cash flow analysis (Net Present Value or Internal Rate of Return) is the appropriate financial tool for project evaluation when benefits are adequately quantified. The COQ framework is useful not only for investment analysis, but also for examining the potential benefits from different uses of the laser scanners. Chapter six reviews the financial analysis performed on several capital investments at Kodak and at three other large manufacturing companies. The last chapter (chapter seven) provides final conclusions and a brief summary of key learnings. Throughout the thesis, the proposed ideas will be applied to the specific case of laser scanner projects in the Roll Coating Division. The next section will describe the initial project goals given by the production manager of polyester manufacturing and some background on the project.

1.2 Background & Project Goals

As an integral part of the education of this student in the MIT Leaders for Manufacturing (LFM) Program, the internship with Eastman Kodak ran from June through the middle of December in 1994. The internship project was within the polyester film base production area at Kodak Park in Rochester, New York. Polyester film base production is part of the Roll Coating Division. This internship was different from the previous internships sponsored by RCD in that the Manufacturing Research and Engineering Group (MR&E) acted as a co-sponsor for the project. A three week orientation period was directed by a mentor from the Polymer Processing Group of MR&E. This was followed by a period of learning about processes in ESTAR[2] Manufacturing and planning the method for data collection. Data collection spanned August to the end of October including a four day trip to the site B manufacturing location. The data was compiled and analyzed in November and presented to the Roll Coating Division Managers in December.

Flying spot laser scanners are used in polyester production as on-line instruments primarily for detection of randomly occurring spot type defects.[3] Prior to the use of laser scanners, visual inspection by line operators was the only method for on-line detection of the defects. At typical line speeds, the line operator would only detect large occurrences of defects. Because the operator would also have other tasks, even large showers of defects could occasionally be missed. The polyester sheet is wound onto cylindrical cores

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[2] ESTAR is a biaxially oriented polyester sheet product typically used as film base. ESTAR is a registered tradename of the Eastman Kodak Company.

[3] For the purposes of this thesis, defects will be categorized as either spot type or scratch type. Spot type defects can be internal or external to the polyester sheet and come in many different forms. Unmelted polymer, polymer skins, and grease on the sheet surface are a few examples of typical spot type defects.

and cut at differing lengths depending on the product being produced. At established time intervals, an audit roll is sent for off-line inspection. The purpose of audit rolls is to monitor product quality and insure production is meeting quality specifications. If the audit reveals an unacceptable level of defects, machine operators will take the necessary corrective actions and any questionable product will be held for off-line inspection. Even though the off-line audits are also done through visual inspection, they are a much more reliable measurement of defects. On the "rewind" machines, the sheet is viewed at slower speeds and the operator can stop and go back and forth through the roll to detect less obvious defects. On-line inspection with laser scanners could be a tremendous improvement for two fundamental reasons:

1) 100% on-line inspection of all rolls with a laser scanner as opposed to the questionable inspection provided by the operators on-line and the off-line inspection of a subset of total production.
2) A small time delay in feedback from on-line inspection as compared to feedback from off-line inspection which could take several hours.

Laser scanners were purchased both to prevent release of defective product and provide earlier detection of defects which could be used to make adjustments to the process. These two objectives can be referred to more concisely as product control and process control.

Since 1987, two different flying spot laser scanning systems have been used for detection of defects in ESTAR production at Kodak Park (KP) and other manufacturing locations (Site B & Site C). The first scanning systems installed at KP were hybrid systems with a front end laser and optical system from Sira, a vendor external to Kodak. The Sira front end sends a voltage signal to a Veredus signal processing unit. Veredus is an internal group at Kodak. In 1987 and 1988, Sira/Veredus (S/V) inspection systems were installed on several production machines at Kodak Park. During the same time frame, an Intec inspection system was installed at Site B. Intec, an external vendor, delivers an integrated system of the front end optics and signal processing. In 1992 an additional S/V inspection system was installed on a production line at KP. Also in 1992, an Intec inspection system was installed at Site C. Most recently, an Intec scanner was installed on a machine that was just being started up for production over the summer of 1994. From the initial installation of the S/V systems all the way up to the present time there have been questions regarding the reliability and detectability of the laser scanners at Kodak Park. In contrast to the experience at KP, the Intec system at Site B was perceived as providing sufficient detectability and good reliability.

Given the previously described setting, the polyester film base production manager at Kodak Park proposed a Leaders for Manufacturing Internship project to perform a comparative evaluation of the two different laser scanner systems. In particular, the student was asked to answer these two questions:

1) Which of the two scanners (S/V or Intec) is the best scanner for future investments?
2) How can Roll Coating maximize the value of the investment in laser scanners?

These two questions, which were the starting point of the internship, led to investigation of the financial justification process for investments in quality improvement projects. Throughout the internship, data collection, analysis, and research were directed towards answering the two questions and investigating the third issue.

2.0 Laser Scanner Technology

This project focused on evaluation of the hybrid Sira/Veredus system and the stand alone Intec system. A complete Veredus inspection system which consists of a front end linear array camera and a signal processing unit could also be used for inspection of the polyester sheet. Sira signal processing with a laser front end or a SIC Optic system would also be options for polyester sheet inspection systems. The integrated SIC Optic laser inspection system was not investigated due to prohibitively high costs, approximately three times the cost of the other systems. In previous evaluations, the Roll Coating Division had analyzed and compared the other options and decided that the Sira/Veredus and Intec systems were superior to the other options. Because RCD Worldwide had built up several years experience with both the Intec and Sira/Veredus systems, there were significant advantages to making future investments in one of these two systems. Although Veredus systems have been used within other production areas of Kodak for several years, the Veredus linear array camera system was not evaluated in this study. The Veredus was not considered due the issue of declining detectability caused by decaying intensity of the light source. A laser light source is not susceptible to this problem of decaying intensity. This chapter starts with a brief description of the type of defects which the scanner is intended to detect. The next section is a technical description of the common aspects of the Sira/Veredus and Intec systems which is followed by sections on the unique components of each system.

2.1 Scanner Detectable Defects

Laser scanners are intended to primarily detect random spot type of defects. In addition, the scanners are expected to detect the more severe types of surface abrasions. Scanners are important for detecting random defects because the other quality monitoring systems are not set up to detect random occurrences of defects. Visual operator inspection at the wind up area of the machine, testing samples from each roll, and off-line inspection of audit rolls will provide detection of repetitive occurrences of defects.

However, these quality monitoring systems are not adequate for detection of randomly occurring defects. Continuous 100% inspection of rolls through the use of laser scanners provides detection of both repetitive and randomly occurring defects on all rolls produced.

Defects can be classified as either spot type or surface abrasions (scratches). Within the broad classification of spot defects are two categories. Internal defects are those defects that are inside of the polyester sheet; these defects will occur during or before the two stretching sections of the polyester sheet making process. These defects can tend to distort the polyester sheet. The second category of spot defects is that of external defects or surface spots. These defects occur after the stretching has been completed and generally do not cause any distortion of the sheet. Typically, a surface spot defect occurs when an extraneous material that has accumulated on part of the machine is deposited on the polyester sheet. Following is a list of spot type defects that the scanner is expected to detect, which was taken from the most recent scanner accreditation document at Kodak Park.

Internal (Pre-stretch)	Surface Spots (Post-Stretch)
Polymer Skins	Oil
Slugs	Sublimate
	Water
	Lint

Relative to spot type defects, abrasions are typically long and narrow. However, there are many different types of abrasion defects. Abrasion defects can occur throughout the polyester sheet making process. Based on the scanner accreditation document, a scanner is expected to detect scratches and cinches. Scratches tend to be longer abrasion type defects while cinches are groups of shorter abrasions.

Occurrences of the wide variety of defect types can lead to a range of different consequences. A few types of film base defects will cause disruptions in the downstream (sensitizing) processing operations. Although disturbance of a sensitizing operation due to a roll coating defect is relatively rare, the consequences of such an occurrence are expensive. The majority of film base defects will not cause a disruption in downstream processing, but cause a defect in the finished product. Many defects in the film base will be detected downstream and cut out in the finishing operation. Thus, certain types of film base defects can be a direct source of waste in the finishing operation. Some defects in the film base will not be detected in downstream operations and make it to the final customer. Defects in the film base can cause product to be unacceptable to the final customer. Monitoring customer complaints (KPIRs) is the typical method of measuring the impact of film base defects on the final customer.

2.2 Laser Scanners - Common Elements

Laser & Optics

The front end design of the two flying spot laser scanners has several common elements. A Helium/Neon laser is projected from a power source, redirected by mirrors, focused by a lens and then reflected off a spinning polygon with mirror facets. The laser beam, which is transmitted through the polyester sheet, will move across the width of the sheet. Each facet of the twelve sided polygon will cause one scan across the sheet.
The laser spot will scan across 100% of the area of polyester sheet because the polygon is spinning at very high speeds of several thousand revolutions per minute (RPMs). A defect in the polyester sheet can have two different types of effects on transmission of the laser light:

1) Blocking of light
2) Scattering of light

A defect that distorts the sheet will tend to cause scattering, and a dark discoloration will tend to block light. The two laser scanner systems use different receiver designs for measuring the light blocking and scattering. Both scanners send an output voltage signal from the receiver to a signal processing system.

Signal Processing

Although the basic designs of the signal processing units for each scanner are different, there are a few features common to both scanners. Voltage signals are filtered to enhance the signal and reduce the noise. After the filters and other signal processing, the signal is checked against a threshold. If a spike in the signal breaks the threshold, then further computations will be performed. A defect is detected and classified based on three items:

1) Does the signal break the threshold
2) Period of time that the signal breaks the threshold
3) Width of the signal spike at the threshold

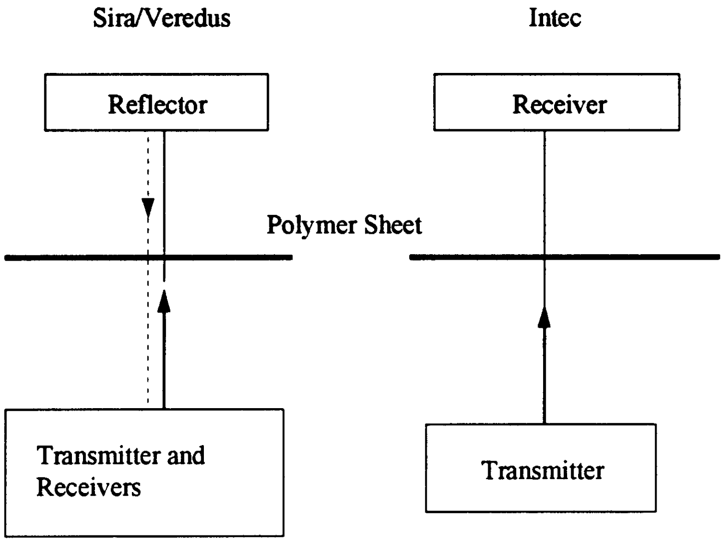
Based on the above data and criteria for classifying defects, a symbol will be assigned to the defect. The symbol will show up through a rolling map on an operator interface screen; it will also appear on a hard copy summary of defects for that roll.

2.3 Sira / Veredus System

Laser & Optics

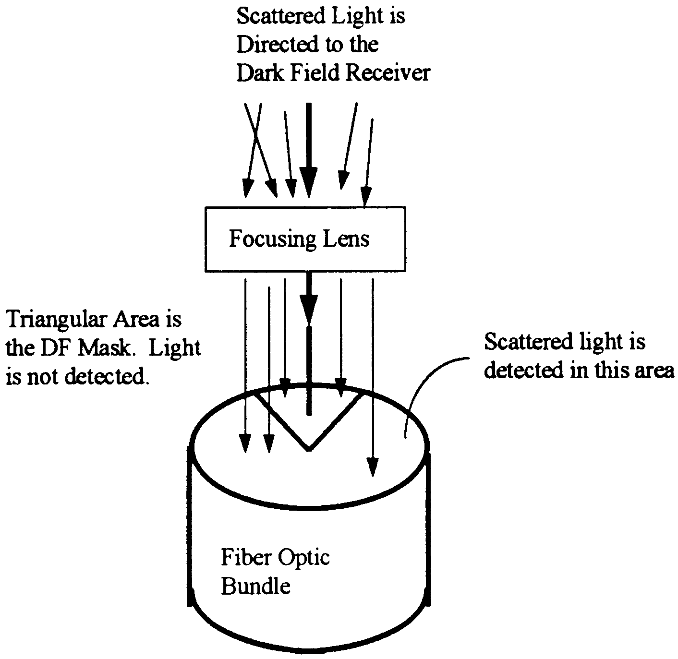
Sira is the laser and optics front end of the Sira/Veredus inspection system. While both the Sira and Intec laser systems are operated in transmission, there is a very significant difference in the design of the receivers for each system. In the Sira system, the laser spot is transmitted from the laser source through the sheet and then reflected back through the sheet to the receiver (see Figure 2.1). The Intec is designed so that the laser beam passes through the polyester sheet once in going from the transmitter to the receiver which is on the other side of the polyester sheet.

Figure 2.1 Laser Path from Transmitter to Receiver



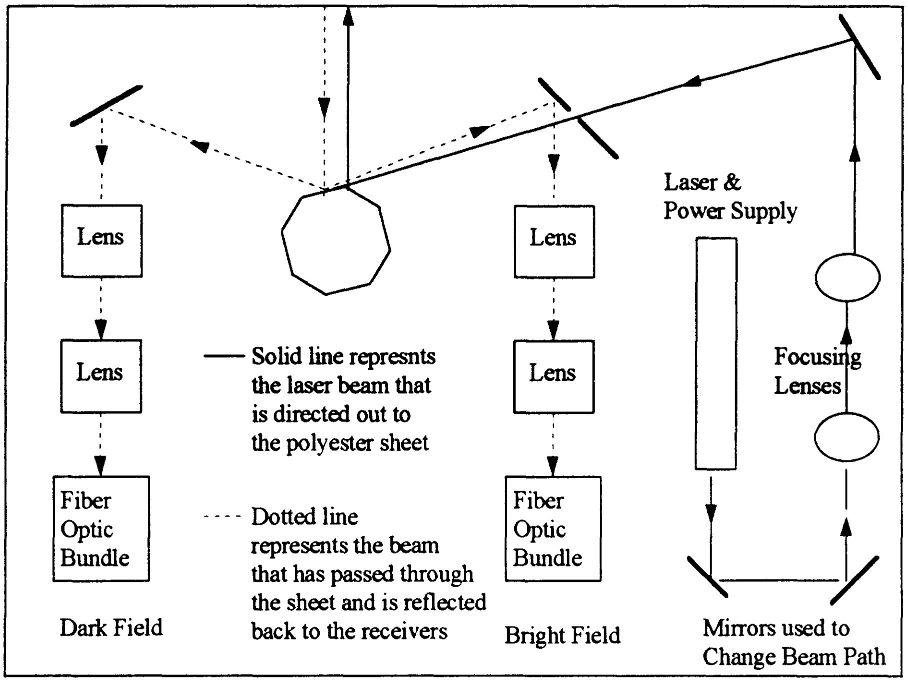
In the Sira design, two separate receivers are used to monitor the reflected signal. The dark field receiver will detect light scattering defects through the presence of light which is deflected off a target spot on a fiber optic bundle. If there is no scattering, the light will hit the target. The target spot is on a mask which prevents the light from contacting the fiber optic cable. Thus, if the light hits the mask there will not be a defect signal (see figure 2.2). In the bright field receiver a decrease in light intensity caused by light blocking defects will be detected on a fiber optic bundle. The term optical bench refers to a set of mirrors and lenses in series used to direct and focus the laser beam. In the Sira design, the laser source, dark field receiver, and bright field receiver optical benches all reside within the same housing (see figure 2.3).

Figure 2.2 S/V Dark Field Receiver



Detectability in the Sira design is sensitive to a number of factors. Alignment of mirrors and lenses in all three optical benches and the placement of masks both affect signal strength and dictate threshold levels. Masks, which are typically made of plastic, are used on focusing lenses and the fiber optic bundles. A dark field mask is placed on the fiber optic bundle so that only light that is scattered off the mask will reach the bundle. The masks are typically constructed by hand without any special tools. Because the dimensions and placement of these masks are not precise, this can be a source of change in signal strength after a preventative maintenance (PM) procedure. The laser tube, power supply, and a component of the receivers are replaced during the yearly preventative maintenance procedures. To perform a PM, all three optical benches are removed from the housing. Changes in alignment of the optical benches can affect the signal strength.

Figure 2.3 S/V Transmitter Housing & Optical Benches



Another difference between the Sira and Intec designs lies in the mirror faced polygon. The Sira polygon is constructed of a glass type of material, and the polygon must be taken out and reconstructed after two years of use. After the polygon is sent back to Sira and reconstructed, it can be reused. The Intec polygon, which is smaller, lighter, and constructed of an aluminum type of metal, has been replaced after four years of use.

Signal Processing

Veredus is the signal processing unit of the Sira/Veredus system. There are a number of significant differences between the Veredus and Intec signal processing designs. One notable aspect of the Veredus design relates to the interface with the Sira front end. The Veredus can only accept a signal within the range of zero to one volt. If a severe defect generates a signal of greater than one volt, the signal will not be seen by the Veredus, which will cause the scanner to miss the defect. From the Sira there is capability to adjust the signal to fall within the zero to one volt range. Nevertheless, this can be a limitation of the Veredus system.

One major difference between the two systems is that the Veredus converts the signal from analog to digital whereas the Intec performs all processing on the analog signal. After the A to D conversion, the signal is sent to a type of digital filter called a convolver. The convolver can be set up to attenuate detection of spot or scratch type of defects but not both. This appears to provide some capability to tune the scanner for detection of certain defects that is not found in the Intec signal processing design. After several processing steps the signal is compared to the threshold to check for the presence of defects. Separate signal processing takes place for the bright field and dark field signals, and different thresholds can be set for each of these signals. Assignment of symbols to defects is based upon the period of time that a signal breaks the threshold and the width of the signal at the threshold. Different symbols are assigned for four different size categories with separate symbols for defects detected in bright field and dark field. Defects show up on line through a rolling map on an operator interface terminal. A set of hard copy summary reports is printed out when the sheet is cut and a new roll is started.

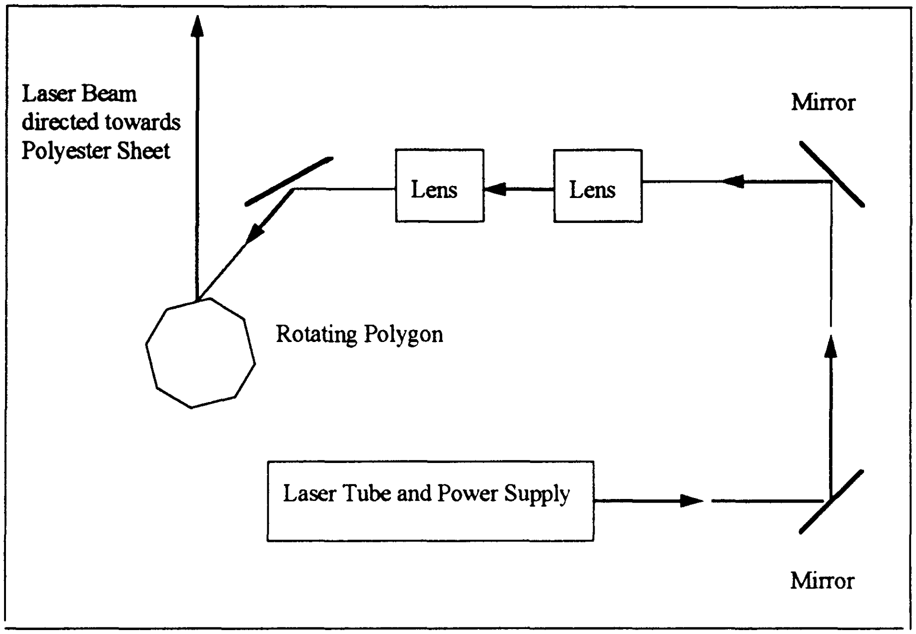
2.4 Intec System

Laser & Optics

One of the major differences between the Intec and Sira systems lies in the design of the receiver. With the Intec system, the receiver is placed on the other side of the polyester sheet from the laser source. Thus, the laser beam makes only one pass through the sheet to the receiver. In contrast to the separate dark field and bright field receivers in the Sira design, the Intec combines the two into a mixed field receiver. The mixed field receiver will generate a single voltage signal. Light scattering defects will cause a positive spike in the signal and light blocking defects a negative disturbance.

Because it does not also contain two receivers, the Intec housing for the transmitter is simple relative to the Sira design (see Figure 2.4). The Intec transmitter housing contains only one optical bench consisting of the laser source, three mirrors, a focusing lens, and the rotating polygon. Preventative maintenance work is done every six months. However, the laser is only replaced every two years and the polygon is replaced after four years of use. Due to the relatively simple design of the transmitter, the standard six month PMs take only a few hours to complete.

Figure 2.4 Intec Transmitter



Detectability with the Intec design can be sensitive to alignment of the laser beam on the receiver and internal alignments of the mirrors and lens in the transmitter housing. Special tools are used to adjust and check alignment of the internal components of the laser transmitter housing. A micrometer system can be used to adjust the position of the laser beam on the receiver. Because there are relatively few factors which affect detectability and there are tools for making exact alignments, detectability is not affected by performance of a preventative maintenance procedure.

Signal Processing

Unlike the Veredus system, the Intec does not convert the analog signal to digital. Instead all processing is done on the analog signal. The voltage signal, which comes from the receiver, is sent through several analog filters to reduce the noise and attenuate any signal spikes.

Thresholding differs on the Intec in several respects from the Veredus. Separate dark field and bright field signals are each compared to their own single threshold levels in the Veredus design. A single voltage signal is evaluated against two thresholds for positive voltage defect signals and two separate thresholds for the negative defect signals in the Intec design. Classification of defects is based on which threshold is broken for what length of time. Width of the defect signal is another piece of information used to assign symbols to defects. The Intec produces both on-line feedback through the operator interface screen and a set of hard copy summary reports at the end of the roll.

3.0 Comparative Evaluation of Scanners

As stated in section 1.2, the initial mission of the project was to answer two questions. A comparative evaluation of the Intec and Sira/Veredus systems was performed to answer the first question: which of the two scanners is the best for future investments? This chapter will describe the five areas of comparison in the evaluation, methods used to collect data in those areas, and results of the data collection. Because reliability has such a significant effect on usefulness of the scanners, another section will be dedicated to that topic. The last section is a conclusion of which scanner delivers superior performance based on the collective results of the five measurements.

3.1 Comparative Metrics

Specific metrics were needed to compare the two scanners and determine which scanner would be best for future investments. Based on initial investigation and input from the ESTAR Production Manager, performance, cost, and potential for future uses were found to be the most important facets of a scanner system. Performance and cost could be measured on a quantitative basis and potential for future uses would be a more qualitative evaluation. Following are the five specific areas in which the scanners were compared:

1) Scanner Accuracy
2) Maintenance Cost
3) Capital Cost
4) Utility of Scanner Output
5) Potential for Future Applications

The next sections contain details on how data were collected and what were the results.

3.2 Comparative Metrics: Methods and Results

Scanner Accuracy

Scanner accuracy was measured by comparing scanner maps for specific rolls to the results of the absolute standard for measurement of defects on a roll. In ESTAR production, the standard for measurement of defects is off line evaluation of a roll on a rewind machine. In the rewind room, a trained operator performs a visual evaluation of the polyester sheet as it is unwound from the roll and rewound onto a new core. The evaluation takes place at a reduced speed relative to on-line production speed, and the rewind operator can slow, stop, and perform additional more detailed inspection at his/her discretion. Although this procedure is susceptible to human error, it is the best available procedure for inspection of the polyester sheet. In this evaluation, data were collected on defects of the smallest objectionable size and all larger sizes (E size or greater). Rewind operators will tend to catch all defects of this size. Since the operators were checking the roll against the scanner maps, they would inspect a section of sheet several times if the scanner map showed a defect in that section. The following terminology was used to describe data from the scanner audits:

HIT - defect indicated by scanner output which was verified by inspection at the rewind machine.

MISS - defect found on rewind inspection for which there was no indication in the scanner output

FALSE CALL - scanner output showed a defect which could not be found upon inspection at the rewind machine.

Defects in the polyester sheet can be classified based on both the size and type of the defect. According to Roll Coating terminology, defect size increases along with the progression of alphabetic letters. For example an F size defect is larger than an E size defect. Data were compiled in separate categories from E size up to G size. All defects larger than G size were put in the same category (G+ category). Defects can come from many different sources and can be given many different labels in polyester sheet production. In this evaluation, defects were classified based on size and placed in one of seven defect type categories (see Appendix A). Comparison of the scanners based on four sizes and seven defect types would be extremely cumbersome. Thus the data were aggregated up into three defect categories with no distinction for size of the defect. Defects occurring before or during the stretching sections of the machine were placed in a pre-stretch category of defects. These defects tended to be more detectable by the scanners because they would frequently cause significant distortion in the sheet. The second category of post-stretch defects tended to be more difficult as they were usually a type of spot on the surface of the sheet which would not distort the sheet. The last category, termed scratches, tended to be difficult to detect because they would cause neither significant distortion of the sheet nor significant blocking of light.

Throughout Roll Coating ESTAR production worldwide, there are a number of Intec and Sira/Veredus scanner systems installed. Laser scanners that had been in operation for several years and were expected to perform well were chosen for both the Sira/Veredus and Intec systems. An Intec system from one production location (not Kodak Park) and a Sira/Veredus system from Kodak Park were chosen as the representative systems. The systems chosen for the analysis will be referred to as the Site B Intec and the KP Sira/Veredus. The specific Sira/Veredus scanner was chosen because it had recently been optimized[4] and was viewed as the best performing Sira/Veredus scanner. In addition, data on an Intec system from Kodak Park were collected. However, data on the KP Intec are not completely representative of Intec performance because this relatively new scanner was still in the accreditation[5] stage when the data were collected. Mixes of different product types are run on all of these polyester machines. All data collected for each machine are from a mix of X-ray and Graphic Arts products.

Data on the Site B Intec come from production during June through the end of August. Scanner audit rolls for the KP S/V were performed from the end of August through late October. Comparatively less data were collected on the KP Intec from the

[4] Optimization consisted of a set of steps to insure proper alignment of physical parts and proper settings on electronic components. The optimization was performed by an engineer from the Process Control Engineering Division.

[5] Accreditation is a period of time when data is collected to measure scanner accuracy, and there are typically minor adjustments to the scanner based on feedback from the data collection.

end of September to the beginning of November. Relative to the number of rolls evaluated, the total number of defects (hits + misses) is higher for site B. This does not indicate higher frequency of defects per square foot of product. Rolls produced at Site B are both wider and longer (on average) which explains the higher defect incidence on a per roll basis. The following table represents a summary of all data collected regarding scanner accuracy (see Appendix A for a complete listing of the disaggregated data)

Table 3.1 Scanner Accuracy[6]

	KP S/V	Site B Intec	KP Intec
Pre-Stretch	92%	100%	94%
Post-Stretch	48%	96%	68%
Scratches	14%	100%*	50%
False Calls	9%	5%	11%
# of Rolls	45	75	23
Hits	175	409	125
Misses	45	8	31

* Only 8 data points

While all three scanners performed well in detecting pre-stretch defects, the Site B Intec clearly outperformed the KP S/V scanner on detection of post-stretch defects, scratches, and level of false calls. The KP Intec showed better detectability than the S/V scanner, but still needs significant improvement to reach the performance level of the Site B Intec. Relative to the Site B Intec, the KP Intec is a newer model with some different features. Thus, thresholds, filters, and other tuning parameters for the KP Intec cannot simply be set to the same values used on the Site B Intec. After initial installation of the

[6] A percentage number is used to describe scanner accuracy for Pre-Stretch, Post-Stretch, and Scratch type defects. This number is the hit percentage which is defined as the total number of real defects detected by the scanner divided by the total number of defects detected upon inspection at the rewind machine.
Accuracy = Hit Percentage = [Hits / (Misses + Hits)] * 100%
False Calls = [(# of False Calls) / (# of defects indicated by scanner)] * 100%

Site B Intec, several years of tuning and improvement were required to reach the current high level of detectability. Given the same amount of time for tuning and improvement activities, there is no reason to suspect that the KP Intec will not approach the performance level of the Site B Intec.

Maintenance Costs

Data on maintenance costs were collected through accounting information kept by the maintenance department. Since the KP Intec had only recently been started up, there were no representative data on maintenance costs. An Intec installation at another location (Site C) in addition to Site B was used to collect data on maintenance costs. The maintenance cost for the KP S/V is actually an average cost over several machines.

Maintenance costs for the laser scanners can come in several different forms. Vendor contracts, in house electrical technicians, and replacement parts were all considered in the calculation of total maintenance costs. Maintenance costs for the Site B Intec were the lowest of the three sites. Total maintenance costs are listed as a multiple of the Site B Intec costs in the following table.

Table 3.2 Relative Maintenance Costs

	Average for Sira/Veredus	Site B Intec	Site C Intec
Annual Maintenance Costs (per machine)	21 X	X	6 X

Holding costs for spare parts inventories were not included in the compiled maintenance costs because the data were not readily available. Based on rough estimations, the holding costs would be low relative to the other components of the maintenance costs. The difference in maintenance cost per machine for the KP Sira/Veredus scanner and the Intec scanner at Site B is very large. Although maintenance cost for the Intec scanner at Site C is not as low as the Site B cost, it was still much less than the cost of maintenance for the Sira/Veredus machines. High cost of the maintenance contract with Sira and the significantly greater amount of time spent on maintenance by in-house electrical technicians are the major reasons why Sira/Veredus maintenance costs are much higher than Intec costs. Costs on the Site C Intec scanner are higher than the Site B Intec because Site B has been using the Intec for four years longer and has moved further down the experience curve.

Capital Cost

Scanner purchase cost and all items associated with installation were counted in the measurement of capital cost. Among the items included with installation costs are engineering/design, project administration, fabrication, and installation. The typical 15-20% of capital cost added as project expense was not included in the measurement of capital cost. The Intec capital cost was based on the 1994 installation of an Intec scanner at Kodak Park. The Sira/Veredus capital cost will be listed as a multiple of the Intec capital cost. For Sira/Veredus, the capital cost was estimated from the 1992 Special Expenditure Request (Kodak's capital request form) for one of the scanners at Kodak Park. The capital cost (in 1992 $) for the Sira/Veredus is 1.46 times (1.46X) larger than the Intec cost. When the Sira/Veredus capital cost is inflated (3% inflation rate) to 1994 dollars, it becomes 1.55 X. Thus, based on capital cost, the Intec is approximately 50% less expensive than the Sira/Veredus.

Scanner Utility

Scanner utility is intended to be a measurement of how well the operators can use the output of the scanner. To measure scanner utility of the KP Sira/Veredus, Site B Intec, and KP Intec, a survey was developed. Operators from the three machine teams evaluated the scanners on a one to five scale. One was the least favorable response and five the most favorable response to a total of five questions on the operator survey (see Appendix B). The KP Sira/Veredus scanner scored an average 3.1, the KP Intec received a 4.0, and the Site B Intec received the most favorable average response of 4.1. Results of the survey should be representative of operator views because over 90% of the operators who use the scanners on each of the three machines filled out a survey. Based on the operator survey, the Intec is easier for operators to use and they are able to better utilize the data it provides.

Future Applications

Evaluation of the scanners for future applications was a qualitative assessment based on the expected needs of new applications and performance of the scanners on previous metrics. In particular, three items that are becoming increasingly important were evaluated. The first item, which is referred to as Remjet, is an application that requires use of the laser in reflection as opposed to the current set up for transmission. Second, inclusions are very small extraneous particles internal to the polyester sheet which are increasingly undesirable for a particular type of product. Surface abrasions such as scratches and cinches are the third item. While scratches and cinches have always been important defects, the laser scanners have not been considered the primary method of detecting these defects. However, as quality standards become tighter and increasing line speeds cause more occurrences of these surface abrasions, the laser scanners will become an important tool for detecting scratches and cinches. In the following table, the Sira/Veredus and Intec scanners are rated for each of these future applications. The evaluations are based on interviews with product engineers, scanner performance in the comparative evaluations, and scanner design. Plus signs indicate the scanner is well suited for the application, and minus signs indicate the converse is true.

Table 3.3 Utility for Future Applications

	Sira / Veredus	Intec
Remjet	-	+
Inclusions	+	+
Scratches & Cinches	-	++

Because it is designed for use in both reflection and transmission (not simultaneously) the Intec is rated as well suited for the Remjet application. The Sira / Veredus, which is not designed for use in reflection, is not well suited for Remjet. Both scanners have the potential to detect inclusions. Detection of inclusions does not imply detection of the group of very small inclusions known as micro-inclusions. With their current designs, these scanners would not detect micro-inclusions. Based on the scanner accuracy data for the Site B scanner, the Intec performs well in detection of scratches and cinches. The Sira/Veredus delivers poor detectability of scratches and cinches. In the qualitative evaluation of the two scanners for three future applications, the Intec again is rated as superior to the Sira/Veredus.

3.3 Reliability & Preventative Maintenance Procedures

Preventative Maintenance (PM) procedures were not a part of the original five metrics used to evaluate scanner performance. However, as more information on S/V scanners performance was collected, it became clear that scanner accuracy could decrease significantly after a PM. Evaluation of the S/V scanner on the first five metrics was done after the optimization but before a PM. After the PM done in November 1994, performance of the S/V scanner deteriorated significantly. During a PM, the optics of the S/V are taken apart. Due to a variety of reasons, the signal from the laser head is different when the optics are reassembled. The change in signal shape and strength requires readjustment of thresholds. Essentially, the scanner must be accredited after every preventative maintenance. Based on Site B's experience with the Intec, detectability does not change, and thresholds are never adjusted after their preventative maintenance procedures. Following is a comparison of the two scanners on items which affect the maintenance procedures.

Table 3.4 Scanner Design & Maintenance

	Intec	Sira / Veredus
Complexity of Design	1 Optical Bench	3 Optical Benches
Special Tools for Alignments	Micrometer Spot Target	Hand adjustments Estimated Alignments
Parts - Frequency of Replacement	Laser Tube - 2 year life Polygon - 4 years	Laser Tube - 1 year life Polygon - 2 years

The above comparison shows the Intec design to be more simple (fewer optical benches) with less frequent replacement of parts. In addition, precision tools facilitate achievement of exact alignment of parts for the Intec. Based on this comparison, the Intec design is simple and more robust (to see the difference in design complexity refer to figures 2.3 and 2.4). Complexity of the Sira/Veredus design and a lack of special tools for alignment of parts provide some insight as to why the signal shape and strength could change after a preventative maintenance procedure. The significant follow up work required to readjust thresholds as well as the lengthy PM procedures lead to the very high maintenance costs observed for the Sira/Veredus. Because the PM procedures are very complex, a representative from Sira is always present for a preventative maintenance. Costs associated with this service from Sira are a large component of the high maintenance cost for the Sira/Veredus.

3.4 Comparative Evaluation: Conclusions

Based on the five metrics of the comparative evaluation and the evaluation regarding preventative maintenance procedures, the Intec clearly delivers superior performance to the Sira/Veredus scanner. On scanner accuracy, which may well be the most important measure of performance, the Intec provides a much higher level of detectability of post-stretch defects and scratches. Maintenance costs[7] for the

[7] Intec costs from the two sites are averaged.

Sira/Veredus are a multiple (approximately six times) higher, and capital cost is 50% higher relative to the Intec. The operator survey and qualitative assessment of the potential for future applications both indicate the Intec is superior to the Sira/Veredus.

In practice, the data clearly indicate that the Intec is delivering superior performance to the Sira/Veredus. What is the theoretical evaluation of the two systems? The Sira/Veredus has some features which the Intec does not provide. In theory, detection of defects through separate dark field and bright field receivers as opposed to the Intec mixed field receiver could provide additional information. This capability would be useful in going beyond detection to identifying the specific type of defect detected. Although the Intec does not have separate bright and dark field detection, it does have two thresholds for positive and two thresholds for negative disturbances in the voltage signal. The Sira / Veredus currently has only one threshold for each field. The digital filter (convolver) of the Veredus provides the other potential advantage of the Sira/Veredus. While the design of the Sira/Veredus does provide some benefit in features, the downside is a significantly more complex design. As borne out by the collection of data, the additional complexity has led to a much less reliable and robust system.

The Sira/Veredus has two features which could provide some utility beyond the Intec design. However, as clearly shown by the comparative evaluation, any theoretical advantages of the Sira/Veredus design have not been realized. The Intec design provides a scanner that is simple and more robust. On all metrics of the evaluation, the Intec delivered superior performance to the Sira/ Veredus. This analysis provides a very clear answer to the first fundamental question of the project: the Intec is the best scanner for future investments.

4.0 Quantifying Benefits and the COQ Framework

This chapter introduces the concept of quality costs and the cost of quality (COQ) framework as used to quantify the benefits of a capital investment. Specifically, the COQ framework will be used to evaluate the benefits of an investment in a laser scanner. To wrap up the chapter, the COQ analysis for laser scanners is compared to conventional calculations used to quantify cost savings due to capital investments in process control/ quality improvement equipment. In this chapter, the term Quality Costs is used to refer to the costs which fall into this type of category. Cost of Quality will be used to refer to the total of all quality costs. The COQ framework is the structure used to categorize all of the quality costs.

4.1 Quality Costs

> Quality costs is the basis through which investments in quality programs may be evaluated in terms of cost improvement, profit enhancement, and other benefits for plants and companies from these programs. In essence, quality costs are the foundation for quality-system economics.[8]

The idea that the benefits of quality cannot be measured is a misconception. Part of the reason for this misconception is that traditional cost accounting does not attempt to quantify quality. A quality cost framework recognizes two sources of costs.

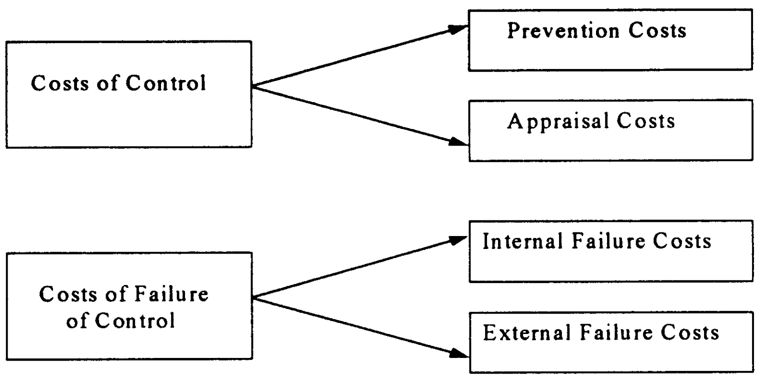
1) Costs required to achieve an objective. i.e. costs required for production of a good.
2) Costs due to imperfect processes and products.

The second category is that of quality costs. Quality costs can be used in department budgets and capital investment evaluations and are occasionally the focus of thrusts to improve business performance. An example of the last point is the emphasis on quality costs as one of three major initiatives put forth by the CEO of Eastman Kodak, George Fisher.

[8] A.V. Feigenbaum, Total Quality Control, (3rd ed., New York, NY, McGraw-Hill, Inc., 1983) p. 80.

As defined by A.V. Feigenbaum, who is widely credited with being the founder of the quality costs system, quality costs fall into the two major categories of Costs of Control and Costs of Failure of Control. The following figure shows how quality costs are further broken down into four major categories.

Figure 4.1 Quality Costs



Based on Feigenbaum's definitions found in Total Quality Control[9], the following are paraphrased descriptions of the four quality cost categories and examples of particular items which would fall in each category:

1) Prevention Costs - expenditures on actions intended to keep defects and nonconformities from occurring in the first place. This category would include investments in employee quality training, efforts to improve process control, and fundamental improvements to the process among other costs which may fall under prevention.
2) Appraisal - costs for maintaining quality levels through off-line and on-line evaluations of product. Regular testing on product samples, quality audits, and special evaluations for questionable product are some of sources of cost which are included in appraisal.
3) Internal Failure - the cost of unsatisfactory product which is thrown away or handled within the defined unit for which the quality costs are calculated.

[9] A.V. Feigenbaum, Total Quality Control, (3rd ed., New York, NY, McGraw-Hill, Inc., 1983) p. 82.

Examples of internal waste would include scrap, reworked material, discards, and machine waste.

4) External Failure - costs of unsatisfactory product which is released and sent to a customer. Product performance costs and customer complaints are among the costs associated with external failure.

As mentioned previously, Quality cost measurements can be used for a wide variety of applications. Quality costs can be used to measure the success of quality improvement efforts, identify areas of low quality with potential for significant savings, and the particular application most relevant in this thesis of quantifying the benefits of improved quality for a capital investment evaluation. When compiling quality costs for any of the above applications, the following are important considerations. Reductions in quality costs should result in a direct savings to the company on a one to one basis. In absorption accounting, overhead is allocated typically as a cost per unit produced. For quality cost considerations, overhead should not be included. Variable cost will usually be roughly accurate as a measure of the direct savings to the company. For the ESTAR production unit at Kodak Park, Out of Pocket (OOP) cost would be appropriate as it takes into account other factors such as excluding material cost which will be regained from recycling.

4.2 COQ Applied to Laser Scanners

In this section, the Cost of Quality framework is defined more precisely for the particular use of quantifying the benefits of investing in a laser scanner. For this use of the COQ framework, the prevention cost will be defined as the capital investment required for purchase and installation of the laser scanner. On going maintenance costs for the laser scanner will also be a part of the prevention costs. Relative capital and maintenance costs for both scanners were given in chapter three.

Potential cost savings due to a laser scanner fall into the other three COQ categories of appraisal, internal failure, and external failure. An overall cost of quality analysis for the polyester sheet production would include many items that are not related to the laser scanner. The laser scanner is not set up to detect product which is not in conformance with regard to thickness and color among many other types of defects. Thus, the scanner investment COQ analysis will only include defects which the scanner could be expected to detect. Machine waste, discards, and other waste metrics for this COQ analysis will be a subset of the total waste numbers because only certain defect categories will be relevant for the laser scanners. The following sections describe how quality costs were obtained for each category and gives the calculated cost or range of costs.

Appraisal

Based on information from the Unit Manager of the rewinders, the rewind operators spend a certain percentage of their time evaluating blocks of rolls which are held due to suspected quality issues. Scanner detection of these defects would allow early detection of the problem and determination of whether product quality is acceptable. Thus, rewinder time spent on blocks of held rolls could be reduced through use of a good laser scanner. In this context a good scanner is one which has a high (>95%) level of detectability and that provides information the operators can readily understand. The calculation of appraisal cost due to rewinder time was based on full rewinder labor costs for all of the crews working the given percentage of their time inspecting blocks of held rolls. The calculated cost for rewinder time is 80% of the total appraisal costs in the COQ analysis.

Similar to the rewinder time spent evaluating blocks of questionable rolls, product engineers spend around 5-10% of their time working with the dispositioning of questionable product. This is also an opportunity for scanner impact in terms of earlier detection and quicker disposition decisions. The conservatively estimated cost for product engineers' time spent dispositioning product was only 12% as large as the cost of rewinder time spend inspecting blocks of held rolls. Even though the cost is relatively small, it may not be appropriate to include the cost of product engineers' time in the COQ analysis. Even if the time spent on evaluating rolls was reduced significantly, this most likely would not lead to any reductions in staff. Thus, product engineers' time is an example of costs that will likely remain fixed (in the short term) and should not be included in the measurement of Quality Costs.[10]

At any given time during the year, there is usually a back log of held rolls to be inspected on the rewind machines. This backlog typically consists of blocks of rolls which are of questionable quality. Rewinder inspection of these rolls provides an assessment of quality which leads to the product release decision. The cost of holding this inventory of rolls for rewinder inspection could be significantly reduced by reliable product quality measurement from an on-line laser scanner. On-line evaluation of product quality enables up front product release decisions and will prevent production of blocks of unacceptable product. The total inventory holding cost was calculated based on an average of monthly held roll inventories for 1993 and 1994, the appropriate OOP cost, and an inventory holding cost of 30% per year. This total holding cost is roughly 20% of the total appraisal costs which include rewinder labor time inspecting held rolls and the inventory holding cost.

Internal Failure

Two metrics were used to measure the costs of internal failure. Discards and machine waste are two major components of total waste. Product that is scrapped due to defects found after it was produced is called discard waste. If the operators are aware of a problem and fixing it while running scrap product, the scrap will be classified as machine waste. In each of these categories, data were collected only for defects that a laser scanner would be expected to detect. Input from several product engineers as well as input from the Process Control Engineering Department was used to determine which defect classes should be included in the data.

An accurate and reliable laser scanner should lead to a significant reduction in discards. The logic behind the previous statement is that if a defect is detected by an on-

[10] The items that should be included in the measurement of Quality Costs will depend on the intended use of the Quality Costs and timeframe of the analysis. The Cost of Quality analysis in this paper will be used to project cash flows from costs savings due to the use of a laser scanner. Thus, the COQ should include only costs that are variable and could potentially be reduced due to effective use of a laser scanner.

line scanner, the operators will either take action to fix the defect or stop production. Thus, accurate, reliable on-line detection of defects will prevent the production of blocks of rolls that are out of specification. The calculated annual cost of scanner detectable discard waste is based on an average of discard waste for 1993 and 1994 (through October). The cost of discard waste is 28% of internal waste in this COQ analysis.

The opportunity for reduction in machine waste due to use of a laser scanner is much lower than the opportunity regarding discards. When a machine is running waste, the operators presumably are already aware there is a problem. However, a laser scanner could still provide value for reducing machine waste. A laser scanner could provide early feedback regarding when a type of defect may be occurring more frequently. Early awareness of less severe defects can allow an operator team to better plan for taking machine waste and fixing the problem. In some cases the operators can fix several problems at one time and reduce the total machine waste. In addition, the scanner can provide feedback on when the problem has been fixed and regular production can resume. Calculation of the cost of scanner detectable machine waste was based on 1993 and 1994 (through October) data. Machine waste is 72% of the total cost of internal waste. Potential reduction of total internal waste due to use of an accurate, reliable laser scanner was taken to be in the range of 10% to 30%.

External Failure

For this analysis external failure will include primarily the costs to downstream internal Kodak customers such as the sensitizing and finishing divisions. The timeframe of this project was not sufficient to perform extensive evaluation on customer feedback from Kodak's final customers. Based on feedback from product engineers and a cursory examination of Kodak's report of customer complaints (also known as KPIRs), the direct cost to Kodak from product failures at outside customers was very low. This direct cost of replacing defective product and other minor items was low relative to the other costs in the COQ analysis. Although the direct costs to Kodak of defective product sent to a customer appear to be low, the longer term effect could be much more significant. If a competitor can demonstrate superior quality, customers who are very quality conscious may choose to change from Kodak to another brand. Even though it is difficult to measure, this type of cost could potentially be significant.

Scanner detectable defects in the film base will almost always be counted as waste in the finishing operation not the sensitizing operation. Thus, waste removed in finishing (WRIF) which is a waste metric from the finishing operation will be used to measure external failure. Sections of film which contain defects are removed in the finishing operation. An evaluation is performed on the defect to determine the source. Responsibility is then allocated to the appropriate area: sensitizing, ESTAR production, or any one of several other areas. While the process for identifying defects and allocating responsibility is not exact, WRIF is the best available source that will provide representative data. The total WRIF assigned to ESTAR production was broken down to waste due to scanner detectable defects. This portion is approximately 30% of the total WRIF allocated to ESTAR production, based on 1993 and 1994 data. On a percentage basis, defect occurrences in the film base sent to downstream customers are very rare. However, the value of the product goes up roughly a factor of ten in the sensitizing operation. Thus, even if the frequency of incidences is low, waste removed in finishing due to film base defects will be very costly. In fact a film base defect cut out in finishing is ten times more expensive than the same defect cut out in ESTAR production.

Aggregate COQ Analysis

The following table provides a listing of the quality costs in each category given as a percentage of the total Cost of Quality. Absolute costs are not given in this thesis because the information is considered proprietary to Eastman Kodak.

Table 4.3 [11] Cost of Quality - Scanner Detectable Defects

	Specific Items	Total Cost
Appraisal	Rewinder Time (Held Rolls) Held Roll Inventory	14 %
Internal Waste	Discard Rolls Machine Waste	65 %
External Waste	Waste Removed in Finishing (WRIF)	21 %
Total Opportunity		100 %

4.3 COQ versus Conventional Methods

Broader scope of analysis is a significant advantage of using the COQ framework versus conventional methods for quantifying the benefits of an investment in quality improvement. Waste reduction is often the basis for justifying equipment expenditures. However, if only cost savings due to internal waste reductions are quantified, the justification could significantly understate the value of an investment. A more enlightened evaluation of project benefits could attempt to quantify the benefits to downstream customers. In this case, the analysis would include both Internal and External Waste. However, this approach still neglects potential savings from reduced product inspection work (Appraisal). For the Roll Coating case of evaluating an investment in laser scanners, the following table shows how the COQ provides a more comprehensive way of capturing the benefits of this particular investment.

[11] The quality cost breakdown provided in Table 4.3 is based on data collected at Kodak Park in 1993 and through the end of October 1994.

Table 4.4 COQ relative to Conventional Measurements

Framework	Percentage of Total Opportunity Captured by Framework
Waste Reduction (Internal)	65 %
Internal and External Waste Reduction	86 %
Cost of Quality	100 %

Cost of Quality is a useful framework for evaluating the potential benefits from an investment in quality improvement. For the analysis in this thesis, the COQ framework is used to evaluate an on-line laser scanner used for detection of defects. After computing the potential opportunity for cost savings with the cost of quality framework, the next step is to estimate the actual savings that can be achieved in each of the COQ categories. A discounted cash flow analysis such as Net Present Value can then be carried out on the projected actual cost savings. This type of analysis will be discussed in the following chapter.

5.0 Financial Evaluation & the Capital Investment Decision

In finance theory, the net present value (NPV) method of analyzing investments is shown to be the correct method of evaluation for maximizing shareholder returns. However, in practice internal rate of return (IRR) is frequently used and other methods are occasionally utilized. This chapter contains a brief evaluation of the strengths and weaknesses of several common investment evaluation methods as well as several keys to successfully using the NPV framework. In addition, characteristics of a typical investment decision process for a large manufacturing company are described. The techniques discussed in the earlier parts of chapter five are applied to the case of laser scanners in the last section.

5.1 Financial Models for Valuing Investments

Although finance textbooks clearly proclaim the virtues of using net present value, several different financial evaluation tools are used in practice. Following are five common methods (including NPV) and a brief definition of each method:[12]

1) Net present value - All cash flows both + and - are discounted back to the present time and added up to obtain the net present value. The discount rate is the opportunity cost of capital or rate of return that could be received from investing in a financial asset that has the same level of risk as the project.
2) Payback - Simple payback consists of counting the number of years until cumulative cash flows equal the initial investment. Discounted payback is different only in the aspect of discounting the cash flows into present value terms.
3) Average return on book value - This measure is a calculation of average income (after taxes & depreciation) divided by the average book value of the investment.
4) Internal Rate of Return - IRR is the project discount rate which will make the net present value of the project cash flows equal to zero.

[12] Definitions of each method are based on the descriptions found in the following reference: Richard A. Brealy, Stewart C. Myers, Principles of Corporate Finance, (4th ed. New York, NY, McGraw-Hill, Inc., 1991), pp. 75-88.

5) Profitability Index - Present value of cash flows divided by the initial investment. This method indicates acceptance of all projects with index greater than one.

Each of these models can be used for absolute evaluation of a project such as all projects with positive NPV have economic value. The five methods are also used for relative comparison of projects according to the logic that a project with higher net present value has greater economic value to the firm.

If NPV is the best financial model, what is wrong with the other models? In both simple and discounted payback, all cash flows after the payback date are not included in the analysis. Simple payback and average return on book value do not consider the time value of money. Average return on book value, which is probably the worst of all five methods, is based not on cash flows but net income. This is inappropriate because net income is dependent on accounting decisions such as the chosen period of depreciation and how costs are identified as either capital or expense. These accounting decisions have no bearing on the economic value of the project. Profitability index will usually lead to the same answer as NPV. However, profitability index can indicate choice of a lower NPV project in the comparison of two mutually exclusive projects. Because internal rate of return is widely used and recommended in some finance texts, a separate paragraph will be dedicated to analysis of IRR and comparison to NPV.

When net present value is a smoothly declining function of discount rate, IRR will give the same indication of project value as NPV. However, if net cash flow per time period changes from negative to positive (or vice versa) more than once over the lifetime of the project, the NPV will not be a smoothly declining function. Thus, IRR will not give the same answer as NPV. In addition, mixed net positive and negative cash flows for different periods can lead to multiple IRRs which make the project NPV equal to zero. For comparison of projects, IRR can indicate choice of a project with lower economic value if the two projects have significantly different cash flow profiles over time. The last disadvantage of IRR relative to NPV relates to the term structure of interest rates. In what is usually considered a normal interest rate environment, interest rates increase as a function of the time to maturity of the debt obligation. In some cases it may be important to consider the term structure and discount long-term cash flows with a higher rate than short-term cash flows. Despite the seemingly significant list of disadvantages, in most situations IRR will yield the same decision as NPV. If the above list of problems, which occur infrequently, is kept in mind then IRR can be a useful tool in the capital investment decision process.

Several simple rules are useful regarding correct use of both NPV and IRR models for project analysis. The first fundamental rule is to base the analysis on cash flows not income. In addition, these cash flows should be incremental relative to the case where the project was not undertaken. The third simple but important rule is to treat costs and revenues consistently with respect to inflation.

As described above, NPV and IRR are useful methods of financial analysis and have been used by more enlightened finance practitioners for many years. As part of the survey of financial methods presented in this section, it is appropriate to mention option analysis. Use of option theory for analysis of corporate finance issues has occurred relatively recently and there are only a small set of forward thinking companies that use this type of analysis. Option analysis is only appropriate for certain types of investments which produce a significant business option.[13] Merck and Co. has applied option analysis to investments in certain types of Research and Development projects.[14] Option analysis is particularly appropriate for this application because at several stages of the project, Merck has the option to continue to invest or terminate the project. Option analysis enables Merck to place a value on the project at each of these decision points. Mining and production of natural resources is frequently cited as an ideal application for real option analysis. In the case of an oil field, given current oil prices, continuing production may not be profitable from a conventional financial analysis point of view. However, continuing to maintain the oil production system will give the company the option to profitably produce oil if prices rise. Although it is not always applicable, option analysis can be a useful financial tool for evaluating projects that provide a significant business option.

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[13] For more on options analysis applied to investment decisions at a manufacturing company, refer to: Craig Belnap, Options Analysis: An Innovative Tool for Manufacturing Decision-Making, MIT Master's Thesis, 1995.
[14] Nancy A. Nichols, "Scientific Management at Merck: An Interview with CFO Judy Lewent," Harvard Business Review, January-February, 1994, pp. 89-99.

5.2 Discounted Cash Flow applied to Projects with "Intangible" Benefits

In the previous section, NPV was shown to be the best tool for project analysis, and IRR was shown to be another useful tool for an educated user. However, many people would question whether these two discounted cash flow (DCF) models can be used to accurately gauge the value of a project with intangible benefits. This viewpoint regarding use of DCF models on projects with intangible benefits is communicated in the following statement:

> Faced with outdated and inappropriate procedures of investment analysis, all that responsible executives can do is cast them aside in a bold leap of strategic faith.[15]

Do statements like the previous one imply that the theory of discounting cash flows is faulty or irrelevant? This is highly unlikely. Receiving one dollar today is worth more than receiving one dollar in the future. The simple but profound concept of the time value of money is certainly a crucial aspect of valuing cash flows distributed over time.[16] If the DCF models are valid then how can NPV or IRR models be effectively applied to projects with intangible benefits?

To address this issue, requires first a description of what falls into the two categories of tangible and intangible benefits. Tangible benefits that will be quantified in a typical capital justification would include savings in labor and materials. A more comprehensive financial analysis may include savings due to reduced energy costs and reduced levels of inventory. Items such as improved quality, greater flexibility in the production process, and lower lead times will be considered intangible benefits. Benefits which may lead to revenue enhancements typically fall into the intangible category.

One of the key elements in an accurate financial project analysis is comprehensive evaluation of the benefits from the project. Quantification of the tangible benefits should be straightforward. Thus, the challenge comes in quantifying those benefits commonly viewed as intangible. One method to capture a broader spectrum of benefits is through

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[15] Robert S. Kaplan, "Must CIM be justified by faith alone?" Harvard Business Review, 64:2, March-April, 1986, p. 87.
[16] Ibid.

the use of broader frameworks such as the Cost of Quality framework. As discussed in the previous chapter, a COQ analysis goes beyond the borders of the immediate production area to capture benefits to downstream operations and external customers. Inventory reductions and more elusive items such as reductions in manual inspection can also be captured in the COQ model. While the COQ framework is very appropriate for the evaluation of laser scanners, other frameworks may be more useful for different types of investments.

Cost of quality is a useful way to quantify several intangible benefits, most notably improvements in quality. How, then can we capture the benefits of more elusive properties such as flexibility and lower lead times? One approach suggested by Robert Kaplan is the following:[17]

1) Compute the cash flows from all readily quantifiable benefits, calculate the IRR, and determine whether it surpasses the hurdle rate. If it passes the hurdle rate then the project can be pursued without further analysis.
2) If the project is not approved after step one, then proceed to determine what additional annual cash flow would be required to meet the financial hurdle rate.
3) Present the project analysis to the manager/ decision maker. Present both the expected intangible benefits and the additional cash flow needed to meet project hurdles. The manager can then answer questions such as, "is the additional production flexibility provided by this project worth $100,000 a year to me?"

Although it does not provide a method to put a dollar figure on the value of flexibility or other benefits, the previously described method is a valuable way to present information to the decision maker. Instead of taking the strategic leap of faith, a manager can make a cognizant decision regarding the value of a specific project benefit.

In performing the financial analysis there are several additional factors that can add or detract from the meaning of the analysis. Due to uncertainty inherent in the prediction of future benefits, a range of possible outcomes is usually more meaningful than a point estimate. This may take the form of calculating several project values with estimated

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[17] Robert S. Kaplan, "Must CIM be justified by faith alone?" Harvard Business Review, 64:2, March-April, 1986, p. 87.

probabilities for each outcome or the form of a point estimate and a sensitivity analysis around that point estimate. As mentioned in the previous section, it is important to perform the analysis relative to the choice of no action. If the project is not undertaken will costs increase or revenues decline? These may be important factors in the analysis.

The first two sections covered the reasons for using NPV and IRR and techniques for capturing the value of "intangible" benefits. The actual investment decision process will be analyzed in the following section.

5.3 The Investment Decision Process

Across different companies the capital budgeting and investment decision processes will have some common components and some idiosyncratic characteristics. One common component is the increasing level of management approval required as the size of the investment increases. Expenditures above a certain level ($ 10-100 K) will require a financial analysis including NPV and IRR calculations. Projects regarding safety or environmental concerns will often be viewed as mandatory and not subject to a strict financial analysis and investment decision process. This section will address the investment decision process not for mandatory projects but for discretionary projects such as the investment in laser scanners.

Based on the financial analysis, the project IRR will be compared to a standard project rate of return threshold called a hurdle rate. The hurdle rate is typically set by a central corporate finance group based on the cost of capital for the particular business or an arbitrary number which is set higher than the cost of capital for a company that practices capital rationing. In a capital rationing firm, a true cost of capital is still required for use as a discount rate in the NPV analysis. The cost of capital should be based on a weighted average of the firm's cost of debt and equity financing which will reflect the overall risk of the business. If the financial analysis is carried out so that cash flows are inflated, an inflation factor should be included in the cost of capital. The cost of capital or discount rate used in financial analysis should be realistic. Using an artificially high discount rate will create a bias in the financial analysis process. Projects with longer term payouts will be unfairly penalized relative to projects with shorter payout horizons. A crucial step to meaningful financial analyses is the correct calculation of the company cost of capital.

Based on a paper by Ross in Financial Management,[18] large manufacturing companies tend to fall into two different categories regarding their capital budgeting processes. The paper entitled "Capital Budgeting Practices of Twelve Large Manufacturers" presents data collected from twelve companies in the steel, paper, and aluminum industries. Based on the findings from this study, companies can be characterized as either flexible budgeting or capital rationing. In the flexible budgeting firms, the hurdle rate set at a corporate level was consistently used for evaluation of projects of all sizes. Project analysis and investment decisions were carried out locally at a relatively low level of the organization.

In the capital rationing firms projects were also analyzed to determine NPV and IRR. However, not all projects with an IRR greater than the company cost of capital were funded. The total capital in the company allocated for investment was determined at a high level of corporate management based only partly on the level of requested capital. The current financial state of the company would have a significant affect on the level of capital reinvested in the business. Thus, factors such as dividend payouts, interest payments, and employee bonuses could significantly affect the level of capital allocated for investment. Because there was not sufficient capital to fund all financially attractive projects, the proposed capital projects would compete against each other for the existing capital. Mandatory projects would be the first projects to receive funding, and discretionary projects compete for the remaining capital. In some cases, arbitrary hurdle rates would be set at levels higher than the cost of capital as a method of filtering out some projects. While the financial project metrics are considered in the investment decisions, strategic considerations also play a significant role in the process of comparing projects. Based on the data in the above referenced article,[19] capital rationing firms tend to change the filter applied based on project size. Larger projects typically were evaluated

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[18] Marc Ross, "Capital Budgeting Practices of Twelve Large Manufacturers," Financial Management, Winter 1986, p. 18.
[19] Ibid.

against more realistic hurdle rates in the neighborhood of 15%. However, small projects (size of between $ 100,000 and $ 1 million) were compared to hurdle rates of 35% and higher. Thus, there was much less investment in small projects, which are typically process improvement and cost cutting type of projects, than was justified by financial analysis. Projects that fell into the category of large projects tended to be new business development or acquisition type of projects. In the study of capital budgeting processes of large manufacturing companies, eight of the twelve companies were classified as capital rationing and four were classified as flexible budgeting. Those results are consistent with other studies which indicate that half or more of large firms follow the capital rationing process. Another consideration worth mentioning is that the four flexible budgeting firms analyzed in the study were all relatively strong financially. If all smaller sized capital projects were significantly more risky, then use of higher hurdle rates would be rational; however, these projects were found to be no more risky than the larger projects. The authors of the study found no rational explanation for the discrimination against smaller projects and concluded:

> Capital rationing is not a rational scheme for focusing effort on the most profitable investment opportunities. Capital rationing is a bureaucratic process which was not responsive at the time of the study to the substantial opportunities for profits offered by small and medium-sized energy-related projects.[20]

As is the case with many processes in large organizations, the capital budgeting process is not purely driven by rational evaluation but also organizational dynamics. The status of the person requesting capital is usually an important factor in capital rationing organizations.

The above analysis provides a description of some important factors which influence the capital budgeting and investment decision processes. One important conclusion from the analysis is that the flexible budgeting approach is a more rational and economically superior process. However, the financial condition of some companies will limit the level of capital available for reinvestment in the business. For the companies that

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[20] Marc Ross, "Capital Budgeting Practices of Twelve Large Manufacturers," Financial Management, Winter 1986, p. 20.

choose to follow capital rationing, the following considerations will help lead to the best investment decisions:

1) Use appropriate financial models (NPV or IRR instead of payback) and follow a consistent evaluation process for all discretionary projects.
2) Put authority for the comparison and decision making process regarding specific projects in local organizations as opposed to centralized decision making.
3) Use a consistent hurdle rate for evaluation regardless of project size.

The above listed set of rules should help to optimize the quality of investment decisions and avoid missing out on small projects with very attractive financial returns.

5.4 Financial Analysis of Laser Scanner Projects

In this section, the principles for financial analysis described in the first three sections of chapter five will be applied to the case of laser scanners in Roll Coating. In particular, the financial tools will be applied to measure the value of three different investment scenarios. The first case will be valuing a project to install a Sira Veredus scanner on a machine that does not currently have a scanner. This case is partly based on the Sira Veredus scanner that was installed on a Kodak Park machine in 1992. In the second scenario, an Intec machine is installed on a machine with no scanner. The third scenario measures the value of an investment to replace an existing Sira Veredus scanner with an Intec.

In all three scenarios, value of the investment will be measured through calculation of both Net Present Value and Internal Rate of Return. Calculation of NPV and IRR requires measurement of both the investment costs and the projected cost savings. Investment costs are based on the capital and maintenance costs that were compiled for both scanners in the comparative evaluation. Positive cash flows (cost savings) are based on the existing opportunity as measured by the cost of quality analysis and an estimated reduction in these quality costs due to use of the laser scanner. Tax rate, discount rate, inflation rate, and depreciation schedule were all based on standard assumptions used for project analysis at Kodak in 1994 (see Appendix C). Although the use of a new scanner will most likely extend beyond five years, evaluating the project based on a five year life is appropriate due to potential changes in scanner technology and increasing demands to detect smaller defects. Both of these factors would tend to limit the useful life of a laser scanner.

Sira Veredus

This case is the evaluation of a project to install a Sira Veredus scanner on a machine that does not have a scanner. The most recent S/V scanner installation took place at Kodak Park in 1992. The initial capital and expense costs for purchase and installation of a scanner were based on the 1992 S/V installation. Scanner operating expenses are simply the annual maintenance costs. In the 1991 capital request, annual costs savings, which were based only on a reduction in internal waste, were estimated to be 10% of the capital investment. This estimate came from a process engineer given his observations of what had taken place after installation of S/V scanners on other machines. Annual cost savings of only 10% of the initial investment are relatively low; however, this was a realistic projection by the process engineer based on his observations of the benefits provided by Sira/Veredus scanners on other machines.

Based on the quality costs analysis in chapter four, internal waste is well over half of the total cost of quality. However, over two thirds of internal waste are machine waste. Due to previously described factors, machine waste will be more difficult to reduce than the other categories of quality costs. Based on the potential impact that a laser scanner could provide towards reducing quality costs in each category, approximately 50% of the reduction in quality costs would come from internal waste. To more fully capture the broad impact of a Sira Veredus scanner the total benefits which include cost savings in appraisal, internal waste, and external waste were estimated to be twice the size of the savings due to internal waste. Total annual savings are estimated to be 20% of the initial capital investment.

Intec

The second case is the purchase and installation of an Intec scanner on a machine that currently does not have a scanner. Both capital and expense costs required to purchase and install an Intec scanner are based on the 1994 installation of an Intec at Kodak Park. The capital required to purchase and install a Sira Veredus is 50% greater than the capital cost of a Intec.

Based on the comparative evaluation, the Intec will deliver significantly better performance relative to the existing Sira Veredus scanners on both detectability and reliability. Installing an Intec scanner on a machine with no scanner will yield the benefits that are realized with a Sira Veredus plus a set of additional benefits due to the superior performance of the Intec. Thus, the positive cash flows consist of a baseline value from the case of the Sira/Veredus and an additional value. The additional cost savings were based on the Cost of Quality analysis. The COQ analysis for Roll Coating was based on machines that currently have Sira/Veredus scanners. Thus, any reduction in quality costs would be incremental to cost savings already realized from the Sira/Veredus scanner. The estimates for reduction in quality costs were based on the difference in scanner performance measured in the comparative evaluation and input from process and product engineers regarding the reduction in different COQ categories. Based on that analysis, results due to an Intec would be a 50% reduction in certain quality costs and a 25% reduction in other quality costs. As described in chapter four, this Cost of Quality only includes items that the scanner can affect. Thus, the COQ referred to here is only a subset of the total of Quality Costs in Roll Coating. To calculate the cost savings for each category, an estimated percent reduction was multiplied by the quality cost for that category. The additional annual cost savings measured broadly through the COQ framework are 38% of the capital required for an Intec.

Intec Replacing Sira/Veredus

The third scenario is replacing an existing Sira / Veredus scanner with an Intec scanner. This case will be similar to the previous case in that the costs will be the same as installing an Intec on a machine with no scanner. However, the benefits will only be the cost savings that are above and beyond the current savings due to the Sira/Veredus scanner. One important additional factor is the difference in maintenance costs between the Sira/Veredus and Intec. Because maintenance expenses are lower for the Intec, this is an additional positive cash flow for this scenario. To be conservative in the analysis, maintenance costs were based on the plant that had experienced higher costs with the Intec. Total additional costs savings due to use of an Intec (lower maintenance and incremental savings from COQ) are 50% of the capital required for an Intec. As in the other cases these cost savings are realized annually.

Results of Financial Analyses

The following table is a summary of NPV and IRR values calculated for each scenario.

Figure 5.1 Financial Metrics for Scanner Projects

	Net Present Value ($)	Internal Rate of Return (%)
Sira / Veredus	-410,000	-12
Intec	340,000	34
Intec Replacing Sira/Veredus	140,000	22

As clearly indicated by the financial metrics, purchase and installation of a Sira/Veredus is not a good investment. The strong NPV and high IRR show that investing in an Intec scanner is economically a highly desirable project. The 22% IRR and positive NPV indicate that the investment in replacing a Sira/Veredus scanner with an Intec is also economically very attractive.

Why are the financial indicators for the Sira Veredus such large negative numbers? Two major factors driving the results are a capital cost 50% higher than the Intec, and an annual maintenance expense that is over 300% higher than the Intec. In addition, the positive cash flows are smaller due to lower performance relative to the Intec.

Sensitivity Analysis

As mentioned earlier in this chapter, an estimate given with tolerance limits or a sensitivity analysis is more meaningful than a simple point estimate. In this case a simple analysis can be useful in showing a project's sensitivity to a decrease in the estimated savings or increase in the estimated project costs. In the previous section, the investment in an Intec scanner for a machine that does not have a scanner was shown to be an economically desirable project. How does the attractiveness of the project change if the capital cost is higher than estimated or cost savings are lower than estimated?

Table 5.2 Sensitivity Analysis

	Original Value	20% Reduction in Cost Savings	Capital Cost 20% Higher
Net Present Value ($)	340,000	180,000	235,000
Internal Rate of Return (%)	34	24	26

Based on the financial indicators shown in the above table, value of the project is more sensitive to changes in projected cost savings than changes in the cost of equipment purchase and installation. In either case, the project still has a high IRR and significant positive NPV.

Although use of the Cost of Quality framework is intended to broadly capture the benefits of the investment, one might still propose that improved quality to the end user cannot be completely quantified. If a manager believes this to be the case, then an investment in scanners might be pursued even if the financial metrics indicate the project does not add value. Based on the financial metrics the investment in the Intec is valuable regardless of additional intangible benefits that were not captured. If the Intec was not available as a choice, the following logic could be applied to the Sira/Veredus investment decision:

1) Sira/Veredus does not meet the financial hurdles
2) However, some intangible benefits were not captured in the analysis
3) Calculate the additional positive cash flow required to meet the financial hurdles.
4) Ask the decision maker whether the intangible benefits are worth the additional required positive cash flow.

For the Sira/Veredus, an additional cash flow of 24% of the initial capital investment per year would be required to achieve break even in terms of NPV (for 12% discount rate) which is equivalent to a 12% IRR. To reach 20% IRR (and NPV of $ 180K) would require an additional cash flow of 34% of the initial capital investment, annually. Thus, the investment decision can be evaluated in terms of the perceived value of the intangible benefit versus the required additional cash flow for an economically valuable project. The above example is purely to demonstrate how this method of evaluating a project with intangible benefits can be applied. The Intec is clearly a superior investment relative to the Sira/Veredus.

5.5 Summary

This chapter has evaluated tools for financial analysis, proposed a framework for evaluating projects with intangible benefits, analyzed some potential disadvantages of the capital rationing approach, and applied these financial concepts to evaluating investments in laser scanners. While Net Present Value was found to be the most rational tool for valuing capital investment projects, Internal Rate of Return is also appropriate for most projects. Comparison of mutually exclusive projects and analysis of projects with cash flows that change signs more than once are the two situations in which IRR should not be used. A Cost of Quality analysis was proposed as a framework to more broadly capture the benefits of an investment. If COQ is viewed as inadequate for capturing all intangible benefits, another approach is proposed for the investment decision. A decision maker can compare the additional cash flows required to meet financial hurdles to the anticipated value of the intangible benefits as a method of evaluating a project. In the third section, firms were described as either flexible budgeting or capital rationing based on their capital budgeting process. Although there appear to be some disadvantages to the capital rationing approach, over fifty percent of large manufacturers follow this process. If capital rationing is used, an important guideline is to evaluate projects against the same financial hurdles regardless of project size. Finally, the financial methods were applied to evaluate investments in Sira/Veredus and Intec scanners. Projects both to purchase and install Intec scanners on lines without a scanner and replacing a Sira/Veredus were found to be financially attractive projects. Based on the financial metrics, an investment in a Sira/Veredus scanner is a negative economic proposition.

6.0 Examples of Project Analysis at Kodak & Other Companies

This chapter presents some examples regarding financial analysis of capital investments at Kodak and three other large manufacturing companies. Several of the projects are investments in on-line inspection equipment that is largely analogous to the laser scanner projects in Roll Coating. Some of the commentary on project analysis is in the form of general principles that are used in the capital investment decision making process. The examples will illustrate both appropriate and inappropriate methods for investment evaluation and decision making.

6.1 Kodak

The capital justification and decision process for several projects in roll coating and one project in the sensitizing division will be examined. These examples will illustrate a range from a project justified primarily on strategic reasons with very little quantification of benefits to a project with comprehensive analysis of benefits.

In the end of 1987 planning and justification activities for capital expenditures on the first laser scanners in Kodak Park ESTAR production were taking place. The relatively low capital expenditures for these projects were in the range of $ 100,000 to $1.0 MM for each scanner installation. Roll Coating had already obtained the Sira laser scanning heads inexpensively from paper sensitizing, and thus the projects consisted primarily of buying and installing the Veredus signal processing units. Apparently, in 1987 the expenditures did not require any quantification of expected cash flows or calculation of financial metrics such as NPV or IRR. Quality was listed as the primary justification in the business case.

In 1991, justification and planning commenced for the installation of an additional Sira/Veredus scanner in Roll Coating. This capital expenditure was significantly larger than the original projects as it included purchase of both the Veredus signal processing unit and the Sira laser head. At this time there was at least a need to quantify some cash flows and calculate the financial indicators. The only savings listed were based on a reduction in internal waste. While expected performance of the new scanner was based on "satisfactory" performance of the existing scanners, the projected waste savings were not connected directly to savings actually realized on the existing machines. The financial analysis for this scanner was questionable in two respects:

1) Quantification of cash flows was limited to the single benefit of a reduction of internal waste.
2) Although several existing scanners had been in operation three years, there was a very weak connection between the benefits actually realized on the existing scanners and the benefits that were expected from the new scanner.

The financial analysis showed a Cash Flow Rate of Return (CFRR), another name for IRR, of three percent. Net present value was calculated to be negative using a twelve percent discount rate. Despite the negative financial indicators, the project was funded. Conclusions from this situation are that there was some need for financial measurements of project value; however, the decision was based primarily on strategic considerations.

At the end of 1993, a capital justification was written to purchase a new plasticator motor for one of the production lines in Roll Coating. The financial analysis was comprehensive in capturing project benefits. Cash flows were quantified for waste reduction, energy savings, and an increase in effective line capacity. A positive NPV of almost $ 100 K and a CFRR of approximately 20% were calculated from the project cash flows. Initial capital outlays for this project were about the same as the original Roll Coating scanner projects and significantly less than the 1991 scanner project. The more comprehensive and detailed analysis was not due to project size. Either there was increasing pressure to financially justify capital expenditures in 1993 or this type of project could not be justified through strategic considerations such as quality improvement. In any case, the type of analysis done on the plasticator motor project provides more information to managers which should lead to better decisions.

Another example of scanner investment decisions can be found in the sensitizing division at Kodak Park. The initial capital outlays for the SIC Scanners used in sensitizing fall in the range of $ 750K to $ 3.0 MM. These investments are significantly larger than the scanner investments in Roll Coating. However, the application of the scanner and potential benefits are very similar to the situation in Roll Coating. Quantification of benefits was very comprehensive in the capital justification from 1992 that was examined. A key element of the analysis was that quantification of benefits was based on gains that were actually realized and measured from other sensitizing lines with SIC scanners. Thus, the benefits could be estimated very accurately. Cash flows were quantified for reductions in waste in sensitizing, finishing (the next Kodak operation), and from customer complaints (KPIRs). In addition, savings were estimated from a reduction in film appraisal. Savings were evaluated from all categories of the proposed COQ framework for capturing the benefits of capital investments. Although it was not called a cost of quality framework, benefits were estimated for appraisal, internal waste and external waste. In addition, two sensitivity type of calculations were carried out. The affects of a reduction in savings and an increase in costs were both calculated. In general, a larger capital project provides more incentive to do a comprehensive detailed analysis. However, this investment analysis illustrates two key elements which can certainly be carried out on smaller projects:

1) Measure the benefits achieved on existing systems and use this to accurately estimate the benefits that will be achieved on the new project.
2) Whether it is explicitly called a COQ framework or not, look for benefits with a broad perspective of where and how the project will have an impact.

The SIC scanner and the plasticator motor project both are examples of project analyses that provide very meaningful financial information.

6.2 Aluminum Sheet Manufacturer

On-line inspection for defects in an aluminum sheet making operation is quite analogous to the use of laser scanners in both the Roll Coating and Sensitizing divisions at Kodak. Managers from the industrial engineering and project engineering groups were interviewed to discover how this aluminum manufacturer uses on-line inspection systems and how the investments in these systems were financially justified. The inspection systems, referred to as Vision Systems, were originally evaluated for two different applications. In one application, the Vision System would be placed at the end of the manufacturing process and would function as a tool for sorting product as acceptable or unacceptable. In contrast to the first application, the Vision System would be placed close to the source of the defects in the second application. Based on their evaluation, this company decided that installation of a scanner that could be used for process control (2nd application) was a valuable investment while the use of a scanner for sorting was not a good investment. Another key component of their decision criteria was impact on the customer. For certain higher value added products (those with special coatings), the customer would value the reduction in defects made possible by use of the Vision System. Scanners were installed on the lines producing coated products.

Because there is a high level of uncertainty regarding the results, the first investment in a new technology is usually the most difficult to analyze. Cost of the first Vision System, greater than two million dollars, was relatively high. Although there was a high level of uncertainty, the aluminum manufacturer did quantify the benefits and perform a discounted cash flow analysis for the project. As part of the process to quantify the benefits, they conducted a customer survey and evaluated previous improvements to on-line inspection capability. Other key components of the analysis were evaluation of competitors and evaluation of the consequences of no action. As mentioned earlier in this chapter, it is appropriate to perform the analysis relative to the case of no action which may be some loss in market share and sales revenue. Because the estimated financial returns were very close to the hurdle rate, the Vision System project had to fit the strategic goals of management. According to the managers who were interviewed, this company went from being "on the ropes" to supplier of the year in eighteen months for a product made on the line with the Vision System installation. The improvement was apparently in large part due to installation of the Vision System.

Analysis and the decision to invest in a second vision system were much easier than on the first Vision System. Due to lower software development costs, the second system was significantly less expensive than the first system. However, a thorough financial analysis with quantified cash flows was performed. An important point is that installation of the first system allows an accurate assessment of the benefits due to a Vision System. This information can be used to perform an accurate financial analysis which can be used to make well informed capital investment decisions. Following are four key learnings from the aluminum manufacturer's Vision System projects:

1) Value of an inspection system may depend on where it is installed in the process (how close to the source of defects). A system used for process control is more valuable than a system used for sorting product.
2) In valuing a project it is important to determine the impact on the customer (will the customer value the type of defects being reduced?)
3) Uncertainty associated with investment in new technologies or systems should not prevent a quantitative analysis and calculation of financial metrics.
4) Data from existing systems should be utilized to perform accurate financial analyses on investments in more of the same systems.

6.3 Automaker

One of the class of 1995 Leaders for Manufacturing students did his internship project on the use of dimensional autobody conformance systems at an automobile production plant. This student was interviewed to learn about the process used at this company to measure the value and make investments decisions for this particular system. The Perceptron system is set up on the assembly line as a station in which lasers are used to check dimensional conformity of the autobody. Ideally, these systems will be used not just to check for conformity to specification but also to provide feedback that will lead to improvements in earlier production stages. Expected benefits from the Perceptron systems, which cost more than $ 500,000, are a reduction in warrantee costs and reduced defects in quality audits such as the J.D. Power Ratings. Financial analysis of this project depends very heavily on the assumptions regarding reduced warrantee costs. Thus, if there is not a good data base which can relate reduced warrantee expenses to installation of Perceptron systems, the financial indicators will involve a high degree of uncertainty. At this auto manufacturer, Perceptron systems had been installed in a large percentage of the auto plants. Apparently, this was driven by a high level manager who believed that these systems were strategically important to manufacturing. This is an interesting example of how a project whose benefits are difficult to measure is pursued because of high level support and belief in a strategic need. The specific production plant is also interesting because it seems to illustrate an effect of capital rationing. Because the plant capital budget was relatively small, it was very difficult for this plant to purchase Perceptrons from the plant budget. Thus, the plant was dependent on using funds from a new vehicle program or a corporate wide quality initiative. In the case observed by the LFM intern, proposed improvements to an existing Perceptron system were to be funded through a "Best in Class" manufacturing fund.

6.4 Electronics Manufacturer

Another class of 1995 LFM student did his internship with an electronics manufacturer. Based on information collected by this student, the plant where he worked had applied a new approach to the evaluation of investments. Cash flow analysis was viewed to be somewhat of an outdated paradigm. The cash flows were considered a second or third order metric whereas projects should be evaluated on first order metrics. Cycle time and direct measurements of quality are two examples of first order metrics. Thus, if a project could be shown to yield a significant reduction in cycle time or a significant reduction in a defect metric, then the project would be approved on this basis. Why would the particular production plant take this approach? One important consideration is the state of their business. When the information was collected, the electronics manufacturer's business was experiencing phenomenal growth. The plant was running at peak capacity, and the primary manufacturing consideration was how to increase capacity and make more product. Although the so called first order metrics of cycle time and defect counts may represent considerable strategic importance, one must still ask if there is not a benefit in financial project analysis. According to the logic proposed earlier in this chapter, the time value of money will still hold, and financial evaluation will be an indicator of the value of a project to the organization (see section 5.2).

7.0 Conclusions

7.1 Comparative Evaluation

Two questions were posed as the basis of a Leader's for Manufacturing student internship:

1) Which of the two scanners (Sira/Veredus or Intec) is the best scanner for future investments?
2) How can Roll Coating maximize the value of its investment in the laser scanners?

A comparative evaluation based on scanner accuracy, maintenance costs, capital costs, utility of scanner output, and potential for future applications, was performed to answer the first question. Scanner reliability was evaluated through an assessment of maintenance procedures and the results of these procedures. On all measures of comparison, the Intec outperformed the Sira/Veredus. Quite clearly, the answer to the first question is that the Intec is the best scanner for future investments.

7.2 Measuring the Opportunity

In the pursuit of answers to the second question, a broader question was asked. In general, how can a manager maximize the value of a capital investment in a quality improvement type of project? To maximize the value of a project one must first find a way to measure the value or potential value of a project. One difficulty with measuring the value of an investment in quality improvement is that a significant component of the benefits tend to be difficult to quantify or even intangible. In addition, the benefits may not be completely local to the group that is making the investment. The Cost of Quality framework was proposed to broadly capture and quantify the benefits of a capital investment in quality improvement.

The COQ framework is useful for measuring the value of an investment. However, the COQ can also be used to determine the largest category of quality costs and hence the most significant opportunity for cost reduction. When the largest opportunities for cost savings have been identified, efforts to utilize the investment can be focused. Concentrating on the most significant opportunities is then one step towards maximizing the value of the capital investment. For the specific case of laser scanners in Roll Coating, use of the scanners can be focused in two major areas. The first is for product control or dispositioning. In this application, the scanner output is used to determine whether or not product is of acceptable quality to send forward to the customer. In the COQ framework, external waste occurs when defective product is sent forward to the customer. Thus, if external waste is a large component of the quality costs, efforts should be focused on using the scanner effectively for product dispositioning. The second major application for scanners is process control. In this application, scanners indicate the presence of defects even if the defects are too small or few to be objectionable. Changing levels of defects can indicate the need for adjustments to the machine. Thus, in process control, scanner output is used to make adjustments to the machine in a feedback type of loop. Some problems can be detected before they become significant and the machine can be adjusted without creating waste. Internal waste will be reduced if the scanner is used effectively for process control. Thus, if internal waste is the major component of the total COQ, use of the scanner should be focused on process control.

When external waste is a significant cost, the scanner should be used to improve the quality of product delivered to the customer. However, it is critical to insure that your quality metrics are aligned with the customers' needs. A statement taken from a BUSINESS WEEK article titled "Quality: How To Make It Pay" illustrates the importance of customer feedback.

> Quality that means little to customers usually doesn't produce a payoff in improved sales, profits, or market share. It's wasted effort and expense.[21]

Although this statement is geared towards the quality delivered to external customers, it most certainly applies to customers within the same company. For the case of laser scanners in Roll Coating, feedback from Sensitizing, Finishing, and even the final customer are all relevant. When external waste is a significant component of the total Cost of Quality, customer feedback is a key element that will lead to maximum value from an investment in quality improvement.

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[21] David Greising, "Quality: How To Make It Pay," BUSINESS WEEK, August 8, 1994, p. 55.

Based on the Cost of Quality analysis, where are the most significant opportunities for scanner impact? Discards and machine waste are the two components of internal waste which is nearly two thirds of the total Cost of Quality. Machine waste is expected to be more difficult to reduce than discards and other sources of waste. However, internal waste is the most significant opportunity for cost savings. Thus, use of the laser scanners should first be focused on process control. In the investment analysis, external waste accounts for twenty five percent of the projected cost savings. Although the opportunity is less than that of internal waste, potential cost savings from a reduction in external waste are very significant. While the primary focus should be on process control, product dispositioning is still an important use of the scanner. Appraisal costs, which are less than twenty percent of the total Cost of Quality, will tend to act as a second order effect. If the scanner is used effectively for process control and product dispositioning, then product appraisal requirements and costs can be reduced.

Quantification of the potential benefits of an investment is valuable because it can provide insight on where to focus the use of the investment. The Cost of Quality framework has value in quantifying and classifying the broader benefits which may be realized through the investment in quality improvement. Based on the COQ analysis, the next step is to focus efforts on the largest opportunities for cost reduction. Thus, quantifying the potential benefits of the capital investment, which can be done through the Cost of Quality framework, is an important step towards maximizing the value of the capital investment. For the specific case of laser scanners in Roll Coating, examination of quality costs indicates that efforts to utilize the scanner should be focused first on process control and second on product dispositioning.

7.3 Investment Analysis

The prior section developed some ideas for how to maximize the value of a capital investment in quality improvement. A closely related and important question is, "What are the key elements of the investment decision making process regarding quality improvement projects?" When faced with a choice between several projects or simply a choice of whether or not to pursue a project, the initial decision can have much greater impact than any future actions in determining the value of the capital investment. Thus, an effort to follow the best process for investment decision making is the logical first step to maximizing the value realized from investing capital in quality improvement projects. This section summarizes key learnings regarding the investment decision making process.

Using the correct financial tools to measure the value of a project is one of the first steps to an effective decision making process. Out of the choice of possible methods, Net Present Value is clearly the best way to measure the economic value of a project. If the user is aware of the few shortfalls of the method, Internal Rate of Return is also an appropriate method for financial analysis of capital projects. The benefits of quality improvement projects can sometimes be difficult to measure. If a significant portion of project benefits cannot be quantified into cash flows then there may be a question as to whether the conventional NPV and IRR frameworks are appropriate for evaluating these projects. Difficulties in quantifying project benefits certainly does not alter the usefulness of the NPV and IRR methods. However, two ideas were proposed to supplement the conventional financial methods for evaluating projects with intangible benefits. Because the benefits of a quality improvement project may tend to occur across different parts of an organization, a broad framework would lead to more representative measurement of the benefits. The Cost of Quality framework was demonstrated to be a useful method of capturing the benefits from an investment in laser scanners. If the use of a broad framework is still not sufficient to capture the value of the investment, there is a second approach to the decision making process. In this approach, the financial tools (NPV, IRR) are used to measure the value of the tangible benefits. Additional positive cash flows required to meet the financial hurdles are then calculated. The decision maker can then evaluate the investment based on the value he/ she would place on the intangible benefits versus the additional cash flows required to justify the project.

Based on the results of other research, companies will follow capital budgeting processes that can be classified as either flexible budgeting or capital rationing. Flexible budgeting appears to be the most rational capital budgeting process. However, due to constraints on the cash flow of the company caused by items such as a heavy debt load, many companies do not have the capital to fund all projects that have economic value. In fact, most of the literature indicates that over fifty percent of manufacturing companies follow the capital rationing process. A common denominator among the capital rationing firms appears to be evaluation against increasingly stringent financial hurdles as the size of the capital expenditure decreases. As expected, the level of detail in the analysis increases with project size. These two factors lead to a discrimination against smaller projects in the capital rationing firms. While a company may be forced to ration capital, projects should be evaluated against the same financial hurdles regardless of size. This will lead to maximizing the economic value of the set of capital investments.

Using the set of principles described in this section, the laser scanner investments in Roll Coating were evaluated. Based on the scanner comparative analysis and the Cost of Quality analysis, the investment costs and positive cash flows were projected for three different cases. Financial analysis indicates that purchasing and installing a Sira/Veredus scanner for a machine with no scanner will yield a negative return on the investment. Both cases for installing an Intec on a machine without a scanner and replacing an existing Sira/Veredus scanner will yield strong positive returns in terms of both positive NPVs and IRRs over twenty percent.

7.4 Key Learnings from Case Studies

Several capital investment projects at Kodak were analyzed to illustrate effective and sometime ineffective financial project analysis. In addition, information regarding the investment decision making process was compiled for three other large manufacturers. Analysis of the cases leads to a number of key learnings which are specific to on-line inspection devices and another set of learnings general to the evaluation of capital investments. Following are two lists of the key learnings:

<u>On-Line Inspection Projects:</u>

1) Focus efforts on process control over product disposition because there is usually a more significant opportunity for cost savings. To maximize the value for process control place the inspection device as close as possible to the source of defects. These

learnings were gleaned primarily from the example of on-line inspection of an aluminum sheet making operation.

2) Learn from success on other projects. This comment refers specifically to the success of Site B in using the Intec scanner. In particular, Site B's use of Statistical Process Control and formalized decision rules enabled very effective use of the laser scanner.

3) Building ownership among the operators and an approach of continually improving the performance of the inspection device are key components of success with on-line inspection devices. This is based on both experiences from the aluminum sheet making operation and the polyester sheet making operation at Site B.

Investment Decision Making Process

1) Results of investments in new technologies or untested equipment have a high level of uncertainty. However, detailed financial analysis will still provide valuable information for the investment decision and may provide important insights regarding how to use the equipment. This was illustrated by the investment in a new technology for on-line inspection of the aluminum sheet making operation.

2) Measure the benefits of an investment in a new technology. Use data from the first investment to reduce the uncertainty regarding the benefits of a second investment in that technology. Effective use of this principle was illustrated by the aluminum sheet manufacturer. The results of ignoring this principle were illustrated by the installation of an additional Sira/Veredus scanner in Roll Coating (1992).

3) Think broadly when measuring the benefits of an investment in quality improvement. Use of a broad framework and also sensitivity analysis are illustrated by the project evaluation of a scanner for the Sensitizing group at Kodak. The aluminum manufacturer provides another example through the use of a customer survey to

evaluate the potential benefits of an investment.

4) The actual capital budgeting and project approval processes at companies are influenced by many factors other than the theoretical maximization of economic value. This can lead to difficulty in funding financially attractive projects and funding of some projects that do not maximize value. At the automaker, capital constraints at the plant level limited the plant regarding investment in a dimensional inspection system. Special circumstances such as one time funding through special quality funds or an upper level project champion were required to gain capital to fund the project. At the electronics manufacturer, some projects are funded without any financial analysis.

7.5 Final Conclusion

At the beginning of the project with Kodak, two questions were posed. The first question was answered through a comparative evaluation. Investigation of the second question led to the issue of how to perform financial analysis on investments in quality improvement projects. Developing ideas for the financial evaluation of laser scanner projects led to some insights for how to maximize the value of this type of investment. In addition, analysis of similar projects at Kodak and other manufacturers provided insights for answering the second question.

The goals of the Leaders for Manufacturing internship at Kodak and the goals of this thesis have been realized. However, the true value of the project to Kodak remains to be determined. Application of the learnings both specific to laser scanners and general to investments in quality improvement projects will determine the true value of the project.

Appendix A Summary of Data on Scanner Accuracy

Data were collected regarding scanner accuracy for the Kodak Park Sira/Veredus, site B Intec, and Kodak Park Intec. The raw data were collected for approximately twenty different types of specific defects. These data were then placed into seven more general defect categories. In this appendix, data are given for each of the three scanners in the seven defect categories. The data given here can be aggregated to a higher level into three defect categories. In Table 3.1, scanner accuracy data are provided for pre-stretch, post-stretch, and scratch type defects.

Scanner accuracy data are collected in terms of hits, misses, and false calls. Following are definitions of each:

HIT - defect indicated by scanner output that is verified by inspection at the rewind machine.

MISS - defect found on rewind inspection for which there is no indication in the scanner output.

FALSE CALL - scanner output indicates a defect that is not found upon inspection at the rewind machine.

Total defects found at rewinder = Hits + Misses

Total defects indicated by scanner = Hits + False Calls

Scanner accuracy is frequently described in terms of percentages. The percentage given to describe scanner accuracy for a given class of defects is typically the percentage of hits.

Accuracy = Hit Percentage = [(# of Hits) / (# of defects found at rewinder)] * 100%
= [Hits / (Misses + Hits)] * 100%

Another term used to describe scanner accuracy is percent false calls. Whereas higher hit percentages indicate superior scanner accuracy, a lower percent false calls will indicate better scanner performance.

Percent False Calls = [(# of False Calls) / (# of defects indicated by scanner)] * 100%
= [False Calls / (Hits + False Calls)] * 100%

Appendix A Summary of Data on Scanner Accuracy

The scanner accuracy data provided in this appendix are listed in seven different defect categories. While many different specific defects could be placed in each category, the following are descriptions of typical defects that would fall into each of these categories.

Polymer Related & Generic Inclusion - pieces of unmelted polymer; polymer skins, strings, and degraded polylmer; small particles of extraneous matter.

U-Coat - inadequate application of a coating; extraneous material in the coating; skins of the coating.

Wheel Sublimate & other - powder or acidic material that has fallen on the soft polymer before either of the stretching operations.

Gel Related - defects related to a coating that is applied to finished sheet; gel skins or extraneous material that entered with the coating.

Tenter Sublimate & Oil/Dirt - sublimate powder, oil, and dirt deposited on the surface of the sheet in the tenter stretching section; spot defects that show up in one initial hit and several "trackoff" or subsequent hits.

Fibers, Skiving, & other - string type of natural or synthetic materials that are deposited on the surface of the sheet

Scratches & Abrasions - long thin scratches in the polymer sheet; groups of short scratches; repeating small scratches.

On the following pages are tables of hit, miss, and false call data for the three different scanners in each of the above described categories.

Appendix A

Scanner Accuracy

Table A.1

KP Sira/Veredus

	E Size	F	G	G+	Total Hits	E Size	F	G & G+	Total Misses	% Hits
Pre Stretch Defects										
Polymer Related & Generic Inclusion	30	38	18	9	95	1	1	0	2	98
U - Coat	14	11	17	11	53	7	1	3	11	83
Wheel Sub & Other	1	0	1	1	3	0	1	0	1	75
Total Pre Stretch	45	49	36	21	151	8	3	3	14	92
Post Stretch Defects										
Gel Related	4	0	1	0	5	3	1	0	4	56
Tenter Sublimate & Oil / Dirt	1	4	3	2	10	8	8	3	19	34
Fibers, Skiving	4	2	1	1	8	1	1	0	2	80
Total Post Stretch	9	6	5	3	23	12	10	3	25	48
Scratches & Abrasions	0	1	0	0	1	3	1	2	6	14

False Calls	17	Total Defects Detected =	175	Rolls Inspected	=	45
% False Calls	9	Total Misses =	45	Average Hit %	=	63

Appendix A
Scanner Accuracy
Table A.2
Site B Intec

	E Size	F	G	G+	Total Hits	E Size	F	G & G+	Total Misses	% Hits
Pre Stretch Defects										
Polymer Related & Generic Inclusion	46	58	13	4	121	0	0	0	0	100
U - Coat	4	12	2	1	19	0	0	0	0	100
Wheel Sub & Other	11	15	2	4	32	0	0	0	0	100
Total Pre Stretch	61	85	17	9	172	0	0	0	0	100
Post Stretch Defects										
Gel Related	34	61	13	4	117	1	6	1	8	94
Tenter Sublimate & Oil / Dirt	19	40	11	3	73	0	0	0	0	100
Fibers, Skiving	2	15	20	3	39	0	0	0	0	100
Total Post Stretch	55	116	44	10	229	1	6	1	8	96
Scratches & Abrasions	0	0	0	8	8	0	0	0	0	100

False Calls	18	Total Defects Detected =	409	Rolls Inspected	=	75
% False Calls	4	Total Misses =	8	Total Hit %	=	99

Appendix A
Scanner Accuracy
Table A.3
KP Intec

	E Size	F	G	G+	Total Hits	E Size	F	G & G+	Total Misses	% Hits
Pre Stretch Defects										
Polymer Related & Generic Inclusion	3	3	8	2	16	0	0	0	0	100
U - Coat	7	15	11	5	38	0	1	1	2	95
Wheel Sub. & Other	0	10	7	1	18	2	1	0	3	86
Total Pre Stretch	10	28	26	8	72	2	2	1	5	94
Post Stretch Defects										
Gel Related	1	2	0	4	7	3	1	0	4	64
Oil/Dirt & Tenter Sub.	4	13	2	0	19	1	10	7	18	51
Fibers, Skiving	6	6	9	3	24	0	0	1	1	96
Total Post Stretch	11	21	11	7	50	4	11	8	23	68
Scratches & Abrasions	0	1	0	2	3	0	2	1	3	50

False Calls	16	Total Defects Detected =	125	Rolls Inspected	=	23
% False Calls	11	Total Misses =	31	Average Hit %	=	77

Appendix B Scanner Survey

Following are the questions used in the operator surveys regarding the Intec and Sira/Veredus scanners. The same set of questions were used in the surveys presented to the different sets of operators who use the KP Sira/Veredus, Site B Intec, and KP Intec.

1) How well does the scanner detect defects?

Misses most Defects				Detects All defects
1	2	3	4	5

2) Are the scanner printouts easy to understand?

Difficult				Easy
1	2	3	4	5

Why or why not?

3) Is output from the scanner used to make adjustments to the machine (cut back & clean tenter, check gel hoppers, etc.)?

No Yes

If yes, how frequently?

Once per month		Once per week		Once per shift
1	2	3	4	5

4) Is it easy to use the scanner computer keyboard and video screens?

Difficult				Easy
1	2	3	4	5

Why or why not?

5) How often do you call memo for help with the scanner?

Once per shift		Once per week		Once per month
1	2	3	4	5

6) Any additional comments on the scanner?

Appendix C Financial Analysis

Appendix C provides an explanation of the methods used to calculate the Net Present Value and Internal Rate of Return financial indicators. Both NPV and IRR are methods of measuring the value of a set of cash flows that are distributed over the lifetime of a project. In the case of laser scanners, the project lifetime is five years. This is a standard lifetime for capital investments in equipment of this type. This time frame is representative of the expected life of a scanner given changing technology and increasingly tough performance requirements.

Both NPV and IRR calculations are based on a stream of net project cash flows. Thus, financial evaluation first requires analysis of all positive and negative project cash flows. The following are brief descriptions of the sources that contribute to project cash flows.

Capital Investment - this is the capital that must be spent by the firm to undertake the project. Typically, the capital will all be spent in the first time period; however, capital can be spent during any of the project time periods. This item is a negative value in the overall summation of net cash flows.

Cost Savings (Revenue) - the benefit or positive cash flow that is created by undertaking the project. For the scanner investment, the positive cash flow is a cost savings. Other types of investments can create increased revenue.

Operating Expenses - usually, there is a significant initial expenditure to undertake the project that is classified as expense instead of capital (10-20% of capital spent). In the following time periods operating expenses will be significantly less. Equipment maintenance can be the operating expense.

Depreciation - equipment depreciation can be deducted from operating income and thus will reduce taxes of the firm. Depreciation must be multiplied by the firm's overall tax rate to find the positive cash flow provided by this tax shield. In this analysis, the five year accelerated cost reduction system (ACRS) is used to calculate depreciation.

Tax Shield - whenever project expenses are greater than revenues (cost savings) there is a loss. The loss will create a tax shield equal to the loss multiplied by the firm's tax rate. As previously mentioned depreciation also provides a positive cash flow through a tax shield.

Net Cash Flow - this is calculated by summing all project cash flows. Revenues minus operating expenses must be multiplied by one minus the tax rate to obtain the cash flow. Tax shield is added and capital investment is then subtracted to obtain the net cash flow for each time period.

Appendix C Financial Analysis

Following are the equations used to calculate Net Present Value and Internal Rate of Return:

NPV = Present Value of Net Project Cash Flows

$$NPV = \sum_{i=0}^{n} \frac{C_i}{(1+r)^i}$$

where n = number of time periods during the lifetime of the project.
Ci = net cash flow for the ith time period.
r = project discount rate; this should be the appropriate cost of capital.

IRR = the discount rate that makes project NPV equal to zero; IRR can be calculated directly using a spreadsheet or it can be calculated iteratively with the following equation.

$$0 = \sum_{i=0}^{n} \frac{C_i}{(1+IRR)^i}$$

Appendix C Financial Analysis

The following table represents a sample spreadsheet for determining net project cash flows; NPV and IRR are calculated for the project. The framework is the same as that used for financial analysis of the scanner projects. However, the numbers used in this example are arbitrary and unrelated to the actual scanner projects.

Basis: Tax Rate = 0.39
Discount Rate = 0.12
Inflation Rate = 0.038
Salvage Value = 0

ACRS 5 Year Depreciation Schedule
Cash flows inflated with year 1 as the baseline

Period	0	1	2	3	4	5
Capital Investment	450					
Cost Savings (Revenue)		200	208	215	224	232
Operating Expenses	60	20	21	21.5	22	23
Depreciation		90	144	86	52	52
Tax Shields	46	35	56	34	20	20
Net Cash Flow	-464	145	170	152	143	147

All numbers are in thousands

Project NPV = $ 84,000
Project IRR = 19%

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