An application of problem solving methodologies for small, low-technology firms

by

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ABSTRACT

This thesis focuses on problem solving methodologies in small, low technology firms using statistical thinking. It examines the different elements of statistical thinking and how owners and managers of small businesses can assess their performance using profit margin as a metric. The literature points to a lack of key parts of knowledge or experience on the part of the owner required to grow a business. On many levels, this is compounded by the attitudes and actions of the owner or manager. However, this research shows that with a tacit understanding of how all work is essentially a series of interconnected processes with variation within each process, one can: (1) categorically measure that variation, (2) identify areas of deficient performance, and (3) aim to improve those areas.

The study uses a Split-Plot/Repeated Measures (SP/RM) design on contracted jobs of an East Coast fabrication and installation firm during the 2002 fiscal year. Data were collected on job type (fabrication/installation) and job scope (sheet metal/other). Every contract is estimated with labor and material estimates; therefore, each job submits two profit margins for evaluation: a labor profit margin and a material profit margin. Using the twenty jobs of 2002, only job type was found to be statistically significant.

Statistical thinking is incorporated into this study by walking the reader through graphical analyses of the data and identifying possible sources and causes of variation. Each chapter has a section dedicated to the use or application of statistical thinking and how it is used in this study.

CHAPTER 1. INTRODUCTION

Rationale

Deming said, "Quality begins with the intent, which is fixed by management" (Deming, 1986, p. 5). Organizations are engaged in a flurry of competitive initiatives that aim to minimize or eliminate unnecessary operational cost while simultaneously improving faster than their competition (Bigelow, 2002). This may be most pressing on small, non-high-tech manufacturing firms struggling to keep their heads above water. Reid (1999) suggests that owners and managers of small start-up businesses consume much of their own efforts and human resources within the framework of production (an average of 41 hours out of an average 58 hour work week) rather than business performance. He comments that some "devote more attention to process than to purpose" (p. 306). The very nature of the business environment has in many ways been transformed into a knowledge-based, global, and hyper-competitive marketplace (Tornatzky, Batts, McCrea, Lewis, & Quittman, 1996). More importantly, there is a notable trend of underinvesting for improved productivity in small, low technology, manufacturing firms (Society of Manufacturing Engineers/Association for Forming & Fabricating Technologies (SME/AFFT), 2002).

Purpose of the Study

The purpose of this research study is three-fold:

(1) Introduce a statistical thinking methodology of investigating small business performance in the form of profit margins

(2) Utilize methodologies, in conjunction with experimental design, on a small, East Coast steel fabrication firm, Mechanical Plus, Inc.

(3) Incorporate statistical thinking into performance measurements for small manufacturing firms as set forth by Britz, Emerling, Hare, Hoerl, and Shade (1996) who suggest that:

1. All work is a series of interconnected processes,
2. All processes vary,
3. Understanding and reducing variation are keys to success.

The investigator's aim is to identify and define a variety of tools available to business owners and managers that facilitate an assessment of current business performance; specifically, profit margins of small, contractual steel fabrication manufacturers in the United States. The criterion for selection of these tools is from the viewpoint of what Hansen and Serin (1997) identify as "the practical man", or one who has the ability of accumulating experience of product and process adaptation through learning by doing:

> Product development in these firms is based on solutions that are not grounded in science, but are more a manifestation of a kind of tacit knowledge the practical man possesses. He often "sketches the product on the back of an envelope." Product development in this type of firm – the small, low technology firm – therefore becomes highly dependent on the experience and skills of the individual and his ability to expand his professional framework of production. (p.188)

In fact, it is this very type of owner and/or manager the researcher wishes to address.

Mechanical Plus, Inc. is a steel fabrication and installation job-shop contractor located in Lancaster, Pennsylvania. The company's annual revenues have been relatively static over the past three years. According to the president of the company, a majority of the revenues are realized through contracted sheet metal products, including, but not limited to: duct work, drip pans, guards, flashing, and insulation. Additional fabricated products include piping, mezzanines, structural steel, and oxidizers. These same items are categorically contracted for field installation as well[1]. The researcher's experience in the fabricated metal products industry, and his direct relationship with Mechanical Plus, Inc. (a family-owned business), are precursors to the motivation of this study. It is further warranted by his position as the Production and Operations Manager at Mechanical Plus, Inc.

To that end, the estimating process at Mechanical Plus, Inc. has been found to be inconsistent and will be assessed in terms of profit margin for both material and labor costs as they relate to actual costs incurred per job. Deliverables from the variance in profit margins will then be used to target specific areas of trouble, and eventually, to reduce the variation of estimating so that, based on the type of work, one can predict the expected overall profit margin with a fair amount of confidence and consistency. In addition, the study will demonstrate the use of statistical thinking as a philosophy of learning and action to encourage small, low technology firm owners and/or managers to consider its use in their business (Britz, et al, 1996).

Before implementing the philosophy of statistical thinking, it is imperative to define the differences, and subsequent relationship, between statistical thinking and statistical

[1] The company occasionally accepts time and material work as well. Due to the non-contractual nature of these jobs, they are excluded from the study

methods. Leitnaker (2000) correlates the differences between statistical thinking and statistical methods to a building contractor:

> Contractors, with their tools, can build bars, barns, and bandstands as well as houses. And in these different applications, the "tools of the trade" are used in different ways. Similarly, statistical methods can be used for a wide variety of purposes...Without the underlying foundation provided by statistical thinking, statistical methods can be ineffective and sometimes even detrimental to improvement efforts. (p. 2)

In Figure 1, Leitnaker (2000) illustrates the differences and the relationship based on the framework of a logical progression of statistical methods from statistical thinking.

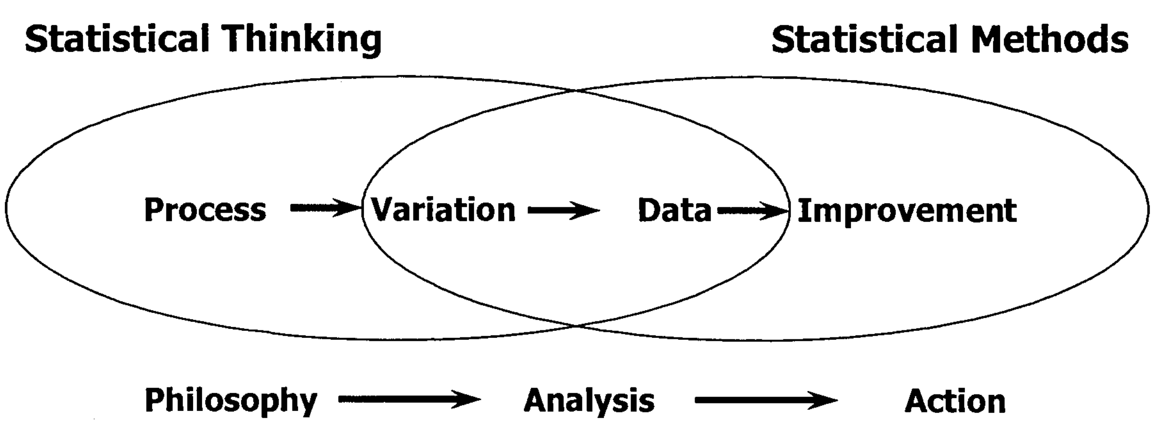

Figure 1. Comparison of Statistical Thinking vs. Statistical Methods (Leitnaker, 2000, p. 2).

Need of the Study

Federal funding has significantly decreased for fabricated metal products from forty-six million in 1999 to forty-one million in 2000 (SME/AFFT, 2002). This negatively impacts both long-term competitiveness of manufacturers and the infrastructure technologies that improve productivity (SME/AFFT, 2002). This sentiment is echoed by Growth and Kinney (1994) who suggest that boosting profits by cost reduction adds far more value than simply increasing profits via pricing. Moreover, innovations in information technologies allow business performance assessment at a lower cost than was previously realized (Growth and Kinney, 1994).

Unfortunately, low technology firms lack research-based knowledge related to their learning processes (Hansen & Serin, 1997). Most of these firms, considered non-R & D, focus on design, engineering, and pre-production developments as sources of innovation and are therefore branded as 'supplier dominated' industries (Sterlacchini, 1999). Roper (1999) finds that owner-managers, a group of partners, or members of a family dominate most small businesses. However, many entrepreneurs and small business owners lack key parts of knowledge or experience required to grow a business (Tornatzky, Batts, et al., 1996). More importantly, small businesses represent 99.7% of all employers with one third of new firms surviving at least two years and only half surviving four years (Small Business Administration, 2003). These figures bear witness to the need of a research study that demonstrates how small, low technology firms can use the tools and methodologies contained herein to assess their current state of affairs, use decision making tools to target problem areas, and, finally, initiate strategic objectives that reduce costs.

Research Questions

The research questions posed by this research are as follows:

Research Question 1

Is there a significant difference in mean profit margins between contracted fabricated jobs and contracted field installation jobs?

Research Question 2

Is there a significant difference in mean profit margins between sheet metal jobs and other jobs[2]?

Research Question 3

Is there any significant interaction between type of job (fabrication/installation) and scope of job (sheet metal/other)?

These research questions are represented as hypotheses in the next section of this chapter.

Hypotheses of the Study

Null Hypothesis 1

There is no significant difference in mean profit margins at the $\alpha = .05$ level between contracted fabrication jobs and contracted installation jobs.

Statistical Hypothesis 1

$$Ho: \mu_{fab} = \mu_{Instal}$$

$$Ha: \mu_{fab} \neq \mu_{Instal}$$

---

[2] "Other" is all other type of work excluding sheet metal. This is based on the recommendation by the president that most of jobs are derived from sheet metal; it also allows for adequate data points for statistical analysis.

Null Hypothesis 2

There is no significant difference in mean profit margins at the $\alpha = .05$ level between the sheet metal jobs and other jobs.

Statistical Hypothesis 2

$$Ho : \mu_{SheetMetal} = \mu_{Other}$$

$$Ha : \mu_{SheetMetal} \neq \mu_{Other}$$

Null Hypothesis 3

There is no significant interaction between the different levels of job type and job scope.

Statistical Hypothesis 3

$$Ho : \mu_{Fabrication*SheetMetal} = \mu_{Fabrication*Other} = \mu_{Installation*SheetMetal} = \mu_{Installation*Other}$$

$$Ha : \mu_{Fabrication*SheetMetal} \neq \mu_{Fabrication*Other} \neq \mu_{Installation*Sheetmetal} \neq \mu_{Installation*Other}$$

Assumptions of the Study

There are four assumptions of the study:

1. All jobs are estimated with a target profit margin of twenty percent.
2. All jobs are estimated by one person thereby controlling for any bias due to variation in the estimating process.
3. Miscellaneous and rental items do not impact profit margins to the extent of labor and material.
4. The jobs contracted during the 2002 fiscal calendar are representative of the type of work the company will continue to contract.

Delimitations of the Study

The study is limited in the following areas:

1. Scheduling and job assignment for the labor were not controlled.
2. Data based on 2002 contracted jobs only.

Procedures of the Study

1. Identify the research problem
2. Develop the Job Cost Analysis for data collection. A copy can be found in Appendix A: Job Cost Analysis.
3. Conduct literature review on small business profitability.
4. Collect data starting from January 2002 through December 2002.
5. Code the research data.
6. Analyze Split-Plot/Repeated Measures Design data with JMP 5.0.
7. Use problem solving methodology tools to isolate and develop strategic initiatives for the company.
8. Write final report, conclusions, and recommendations based on analysis.

CHAPTER 2. LITERATURE REVIEW

Overview

Chapter Two is an overview of the literature. To ascertain the current state of knowledge for small, low technology firms, the researcher selected topics that serve both the immediate study (Mechanical Plus, Inc.) and the implications it would have on similar businesses. The following lists those topics in order of presentation:

- Statistical thinking
- Decision making tools
- Small business profitability
- Innovative and research and development initiatives in low technology firms

Statistical Thinking

> "Statistics" is not merely a set of techniques to be used solely on projects. So, forget all the statistics you learned in school. The messy real world is quite different from the sanitized world of textbooks and academia. And the good news is that the statistical methods required for everyday work are much simpler than ever imagined...but initially quite counter-intuitive. Once grasped, however, you have a deceptively simple ability and understanding that will ensure better analysis, communication, and decision making. (Balestracci, 1998, p. 1)

Commenting on operational excellence, Bigelow (2002), recommends returning to the basic building blocks of any organization: establishing requirements, communicating requirements, and finally, assessing those requirements. Excellence, in any form, requires commitment, and for business it was stated best by Deming (1986):

> It is not enough that top management commit themselves for life to quality and productivity. They must know what it is that they are committed to – that is, they must do. These obligations can not be delegated. Support is not enough: action is required. (p. 21)

Townsend and Gebhardt (2002) reiterate Deming's position of commitment by stating:

> Commitment means the willingness to invest one's self – one's own ego, time and effort. It does not mean the willingness to sign amazing checks for consultants or go to a school in some tourist area for two weeks before turning things over to the consultants. (p.77)

They continue with four business reasons for quality:

1. It makes money. It reduces waste and increases sales once the word gets out about the quality.
2. It results in loyal customers. They stay longer, bring their friends and will forgive you – up to a point.
3. It results in loyal employees. This reason has the same advantages as no. 2.
4. It is the ethical choice. After all, what a quality process amounts to is making it possible to deliver exactly what you promised. This is not a complex undertaking. (p. 79)

Statistical thinking is a philosophy by which information is viewed, processed, and converted into action, and not a means to perform mathematical calculations (Britz, 1996). Leitnaker (2000) emphasized the importance of this philosophy in the context of an industrial process when she comments, "...practitioners often apply inappropriate statistical methods (such as performing ANOVA on unstable processes), which at best minimize their impact on improvement, and at worst, lead to poor decisions and mistrust of statistics" (p. 1). This is further qualified by Balestracci (1998) that statistical thinking adds to the knowledge base from which to ask the right questions, and refers to process-oriented thinking as a key concept in statistical thinking; that all work is a process. This premise stems from the three fundamental principles of statistical thinking (Britz, et al., 1996, p. 5):

- All work occurs is a system of interconnected processes,
- Variation exists in all processes, and
- Understanding and reducing variation are keys to success.

"These principles are fundamental in the sense that the philosophy being applied cannot be Statistical Thinking unless all three are incorporated" (Britz, et al, p. 6).

The principles of statistical thinking are conceptually simple (Balestracci, 1998) and do not require the use of advanced math or statistics for successful incorporation into a low technology small business environment. One needs only the ability to recognize that their business consists of processes that can be defined, measured, and analyzed. Even the "practical man" that sketches on his or her napkin (Hansen and Serin, 1997) works through a process. In fact, sketching on the napkin may be the first element of a bigger process.

Walter Shewhart, a renowned physicist at Bell Labs during 1920s and 1930s and a quality guru, recognized the relationship and link between manufacturing process variation and performance of products (DeVor, Chang, & Sutherland, 1992). Fifty years before the quality movement in the United States, Shewhart comments on the importance of reducing variation:

> Shewhart speaks of the economic control of manufacturing operations and of the use of the variation pattern of product and process quality characteristics over time. That the process was driven solely by a constant system of forces of variation was deemed necessary by Shewhart to guarantee the economic success of the process. (DeVor, et al., 1992, p. 10)

The broad applications of statistical thinking extend beyond the manufacturing floor and can be used throughout the service industry, in education, and in one's personal life as well (Britz, et al., 1996). The manner in which it is used in industry can be categorized based on the level of activity and job responsibility (Britz, et al., 1996). They recognized three interconnected levels of the use of statistical thinking: Operational, Managerial, and Strategic – See Figure 2.

Figure 2. Use of Statistical Thinking (Britz, et al., 1996, p. 7).

Decision Making Tools

In the Preface to their book, "Root cause analysis: improving performance for bottom line results" Robert and Kenneth Latino (2002) commented, "Corporations set earnings expectations, plants set production goals, or hospitals set expected profit margins; whatever the case, they all set the bar at a certain level. Once the bar is set, all plans revolve around it." This section presents a brief introduction to tools that guide decision making. For production and operations, making decisions fall under two major areas: strategic and operational/tactical. Strategic planning and decision making involves longer time horizons while operational/tactical decision making is more concerned with a shorter time horizon (Jayaraman & Srivastava, 1996). The authors further explain that strategic decision making (longer term horizon) is considered unstructured while operational/tactical decision making (shorter term horizon) is considered highly structured – See Figure 3 below.

There is a collection of seven graphical tools, known as the "seven tools of quality" (ASQ, 2003) that take statistical thinking from paper to practice. These tools help define, analyze, and improve processes that generate quantitative data (Okes, 2002). They can be divided into two sections: Process Description and Process Summarization. The following pages contain a brief description of each tool as defined by the American Society for Quality (2003); an example of each is found in Appendix B.

Unstructured — Semi-structured — Highly structured

Strategic		Operational
Process choice	Facility location	Short-term capacity planning
Process design	Facility layout	Distribution
Product design	Project management	Scheduling
Quality planning	Long-term capacity planning	Quality control
	Aggregate planning	Maintenance
	Long-term forecasting	Short-term forecasting
		Purchasing

Figure 3. Decision Making in POM (Jayaraman & Srivastava, 1996, p. 33).

Process Description

Flow Chart – "A graphical representation of the steps in a process. Flowcharts are drawn to better understand processes" (ASQ, 2003).

Pareto Chart – "A graphical tool for ranking causes from most significant to least significant. It is based on the Pareto principle, which was first defined by J. M. Juran in 1950. The principle, named after 19th century economist Vilfredo Pareto, suggests most effects come from relatively few causes; that is, 80% of the effects come from 20% of the possible causes" (ASQ, 2003).

Cause and Effect Diagram – "A tool for analyzing process dispersion. It is also referred to as the "Ishikawa diagram," because Kaoru Ishikawa developed it, and the "fishbone diagram," because the complete diagram resembles a fish skeleton. The diagram illustrates the main causes and subcauses leading to an effect (symptom)" (ASQ, 2003).

Process Summarization

Histograms – "A graphic summary of variation in a set of data. The pictorial nature of the histogram lets people see patterns that are difficult to detect in a simple table of numbers" (ASQ, 2003).

Scatter Diagram – "A graphical technique to analyze the relationship between two variables. Two sets of data are plotted on a graph, with the y-axis being used for the variable to be predicted and the x-axis being used for the variable to make the prediction. The graph will show possible relationships (although two variables might appear to be related, they might not be: those who know most about the variables must make that evaluation)" (ASQ, 2003).

Check Sheet – "A simple data recording device. The check sheet is custom designed by the user, which allows him or her to readily interpret the results" (ASQ, 2003).

Run Chart – "A chart showing a line connecting numerous data points collected from a process running over a period of time" (ASQ, 2003).

Three process improvement tools, or programs, are worthy of mention as decision-making tools. Although champions of each program appear to downplay the other, the montage of tools and philosophies between the three create an illusion of conflicting strategies (Nave, 2002). Six Sigma, Lean Thinking, and Theory of Constraints are three models with one goal: process improvement. Nave (2002) summarizes their methodologies in the following manner:

Six Sigma – The objective of six sigma is to focus on the reduction of variation that will, in turn, solve both process and business problems.

Lean Thinking – Sometimes referred to as lean manufacturing, this methodology focuses on the removal of waste, or anything not necessary to produce the product or service.

Theory of Constrains – Focusing on system improvement, the methodology of the theory of constraints is preceded by the first principle of statistical thinking: all work occurs is a system of interconnected processes. Identifying the weakest part of the system (the constraint) thereby classifies the strength of the overall process.

Table 1 below summarizes Nave's (2002) comparison of the three process improvement programs.

Table 1.

Comparison of Improvement Programs (Nave, 2002).

Program	Six Sigma	Lean Thinking	Theory of Constraints
Theory	Reduce Variation	Remove Waste	Manage constraints
Application guidelines	1. Define 2. Measure 3. Analyze 4. Improve 5. Control	1. Identify value 2. Identify value stream 3. Flow 4. Pull 5. Perfection	1. Identify constraints 2. Exploit constraints 3. Subordinate processes 4. Elevate constraint 5. Repeat cycle
Focus	Problem focused	Row focused	System constraints
Assumptions	A problem exists. Figures & numbers are valued. System output improves if variation in all processes is reduced.	Waste removal will improve business performance. Many small improvements are better than systems analysis.	Emphasis on speed and volume. Uses existing systems. Process interdependence.
Primary effect	Uniform process output.	Reduced flow time.	Fast throughput.
Secondary effects	Less waste. Fast throughput. Less inventory. Fluctuation-performance measures for managers. Improved quality.	Less variation. Uniform output. Less inventory. New accounting system. Flow-performance measure for managers. Improved quality.	Less inventory/waste. Throughput cost accounting. Throughput-performance measurement system. Improved quality.
Criticisms	System interaction not considered. Processes improved independently.	Statistical or system analysis not valued.	Minimal worker input. Data analysis not valued.

Small Business Profitability

In light of the fact that an owner-manager, partners, or members of a family dominate small business, it is advantageous to interpret those mechanisms or business processes by which individual factors influence business performance (Roper, 1999). That profitability, and its causes, is a central issue in disciplines that study business firms (Laverty, 2001), further qualifies benefits of cost management systems that aim to reduce business risk (Groth and Kinney, 1994). However, there exists a significantly negative effect of the introduction of management accounting systems which otherwise proved robust (Roper, 1999). Groth and Kinney (1994) suggest that boosting profits by cost reduction has greater impacts on the bottom line than an increase from pricing. Roper (1999) refers to factors (groups) that determine a small firms course of action that ultimately lead to performance characteristics similar in nature to those who have taken the same course. His four groups are listed below:

1. The firm's strategic legacy or market position at the end of the previous period,
2. The characteristics, resources, motivation, and attitudes of the owner-manager,
3. The specific business targets or objectives of the owner-manager,
4. The anticipated operating environment that includes competitive position as well as capital requirement or new entrants.

Of special interest to small, low technology firms are the characteristics, resources, motivation, and attitudes of the owner-manager (Group 2). Roper (1999) finds that in terms of profitability effect, owner-managers willing to share power and the educational background of the owner-manager both have positive effects on profitability. Conversely, firms having an increased emphasis on hierarchic managerial techniques of directly supervised work had a negative impact on both growth and profitability. Dhawan (2001) notes the greater efficiency of small firms compared to their large counterparts when defining size in accordance with a firm's assets. This, in turn, realizes about a one and a half percent greater gain in profit rate of small firms in comparison to large firms (Dhawan, 2001).

Laverty (2001) tested the hypothesis that a larger market share was associated with higher profitability. His results failed to support the hypothesis. "Instead, the process that appears to be at work involves what Rumelt and Wensley called "shocks" and Jacobson and Aaker called "unobserved effects". Factors such as luck and management skill simultaneously affect both share growth and change in performance" (Laverty, 2001). In a survey conducted between 1991-1994, about fifty-percent of firms had increased the importance of reasoning, feedback, and agreement by moving away from hierarchic managerial approaches (Roper, 1999). Reid (1999) supports this transition with attitudes and adoptions towards running a business being important. The following is a brief summary of his findings of owners-manager: that providing an alternative to unemployment, to be one's own boss, and to satisfy the need for achievement all have a negative effect on survival. Reid summarized it in the following manner:

> "...it was found that "life-style" based attitudes to running a business (e.g. control-driven motives) were inimical to survival. On the other hand, a willingness to sacrifice profit for growth (arguably a willingness to subordinate short-run profit seeking to long-run profit seeking) was significantly linked to staying in business. (p. 313)

Innovative and Research and Development Initiatives in Low Technology Firms

"...Innovative efforts of small firms belonging to non-R & D intensive industries do matter, even though they focus on activities different from R & D" (Sterlacchini, 1999, p. 830). The capacity to be innovative in a small firm is an important characteristic (Reid, 1999). The innovation process, however, takes on a different form from that of high-technology firms (Hansen & Serin, 1997). Especially in a tough economic climate where job shops face more challenges when competing for business (Waurzyniak, 2002) and technology discussion is focused on high technology products (Hansen & Serin, 1997), low technology firms must constantly improve by devoting financial and human resources to design, engineering, production, and cost-effective capital equipment (Sterlacchini, 1999).

Hansen & Serin (1997) support the advantages of innovation from the practical man and his, or her, low costs of development, which, in turn, assimilate an equally low volume requirement. They do, nonetheless, advocate limiting the extent to which the practical man can develop to where the division of labor in the firm increases more than his or her experience can handle. Reid (1999) found that a minority of about thirty-seven percent of entrepreneurs successfully adopt new technology; though only fifty-three percent had typically adopted new technologies since startup. Considering that small and competitive enterprises constitute a significant portion of our economy (Reid, 1999), it is no wonder that innovative activities in small, low technology firms are found to be important (Reid, 1999; Sterlacchini, 1999; Hansen & Serin, 1997).

CHAPTER 3. METHODOLOGY

Overview

This chapter introduces the method by which data were collected and analyzed. The profit margin data are used to demonstrate the applicability of statistical thinking and statistical methods in the studied environment. A Split-Plot/Repeated Measures design was used to determine the business area whereby performance, measured in terms of profit margins, existed at levels below expected, or estimated, costs. In every contract, labor and material costs are estimated by a single person (in this case, the owner), and a twenty-percent profit is added to every job.

Data Collection

Data for this study were collected from January 2002 through December 2002 on the twenty (20) contracts[3] the firm started and completed that year. A Job Cost Analysis sheet (See Appendix A: Job Cost Analysis), was developed for the study. Each job was divided into three sections:

1. Labor
2. Material
3. Miscellaneous (not shown)

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[3] Note: These include only those jobs that required a contractual agreement between Mechanical Plus, Inc. and the client before the beginning of the job. It does not include per diem (time and material) tasks and/or jobs.

The miscellaneous section included those items in which neither labor nor material could be identified. For example, rented equipment (scissor lift, forklift, crane, etc.) is only occasionally needed on certain jobs; therefore, insufficient data exists to evaluate the efficacy of those profit margins. A review of the data shows very little deviation of the actual costs versus the estimated costs of miscellaneous items. Furthermore, profit was not always added to the cost of rental or miscellaneous equipment. Other miscellaneous items include subcontracted tasks (electrical, software, utilities, etc) where a quote was submitted to Mechanical Plus, Inc., and the direct and indirect incurred costs of labor and material were absorbed by the subcontractor. Estimated costs include a twenty percent margin and are essentially the sell cost. The difference between the estimated cost (including twenty percent margin) and the actual cost (excluding twenty percent margin) divided by the estimated cost formulate the profit margin and is illustrated using the formula ($Profit\ Margin = \frac{Estimated\ \text{-}\ Actual}{Estimated}$). For the purpose of this project, labor margins were standardized as a control mechanism. Using estimated hours versus actual hours, the researcher was interested in the consistency with which the estimator could estimate each job regardless of job size or cost. For example, a profit margin of ten percent on a \$10,000.00 job (\$1,000.00) is weighted equally with a loss of twenty percent on a \$500.00 job (-\$100.00). The mean of the profit margins is $\frac{\boldsymbol{.1\ (profit) + -.2\ (loss)}}{\boldsymbol{2}} = \boldsymbol{-0.05\ or\ 5\%\ loss}$; however, the financial difference is \$1,0000.00 (10% profit) - \$100.00 (20% loss) = \$900.00. Financial information is standardized in the form of profit margins to protect the privacy of the firm; therefore, a negative profit margin does not necessarily indicate financial loss, and vice versa.

Table 2 below illustrates the Split-Plot/Repeated Measures design. Eight treatment combinations are derived from the study. Fabrication and installation are considered the whole-plot factors, whereby sheet metal and other are each considered a sub-plot factor. Each job contributes both a labor and a material profit margin and is nested within the treatment combination thereby resulting in the eight treatment combinations. During the 2002 fiscal year, the firm contracted fifteen (15) fabrication jobs versus five (5) installation jobs.

Table 2.

Experimental Design

	INSTALLATION		FABRICATION	
	Sheet Metal	Other	Sheet Metal	Other
Labor				
Material				

Sample Sizes

Of the fifteen fabrication jobs, seven are classified primarily as sheet metal task structure. In terms of installation sheet metal jobs, only two of the five installation jobs are classified as sheet metal task structure. The remainder of the jobs under both job types is recognized as "Other" as defined in Chapter 1 of this study. Consequently, an unbalanced design is realized with a minimum of two (2) sample sizes in two of the eight treatment combinations. Table 3 shows the individual and overall samples sizes for the different factors.

Table 3.

Sample Sizes

	Sheet Metal	**Other**	**Sheet Metal**	**Other**	
Labor	2 samples	3 samples	7 samples	8 samples	**20 Labor Samples**
Material	2 samples	3 samples	7 samples	8 samples	**20 Material Samples**
	10 Installation Samples		**30 Fabrication Samples**		

4 Inst.(Sheet Metal) + 14 Fab.(Sheet Metal) = 18 Sheet Metal Samples

6 Inst (Other) + 16 Fab (Other) = 22 Other Samples

Using Nelson's Sample Size Tables for Analysis of Variance (1985), Table 4 demonstrates the size of the smallest detectable differences for each combination and factorial efficiencies resulting from the Split-Plot/Repeated Measures Design introduced above.

Table 4

Detectable Differences of Resulting Sample Sizes[4]

Treatment	# of Levels	Minimum Samples	Δ/σ	a	b
Treatment Combinations	8	2	3.0	0.05	0.5
Type (Fabrication or Installation)	2	10	1.8	0.05	0.05
Scope (Sheet Metal or Other)	2	4	3.0	0.05	0.1
Material or Labor	2	20	1.2	0.05	0.05

Data Analysis

JMP 5.0 was utilized in the analysis of the data. A Split-Plot/Repeated Measures design was analyzed with profit margin as the response variable.

Statistical Thinking Application

The use of statistical thinking is incorporated into this study with the development of histograms and a cause and effect diagram of the possible causes of variation in mean profit margins. Five sections were identified and labeled in the following manner:

- Operators
- Machine
- Environment
- Methods

[4] Values of a & b correspond to Type I and Type II errors of Hypothesis Testing, respectively.

[6] 20 contracted jobs. Each job has a labor profit margin and a material profit margin for 40 data points.

- Management

The function of the diagram is a precursory assessment of future studies to reduce the variability of profit margins in contractual labor and material costs, and realizing a more efficient and effective estimation process.

CHAPTER 4. FINDINGS

Overview

This chapter summarizes the findings of the statistical analysis relative to the research questions posed in the first chapter of this study. Exploratory data analysis, inferential statistics, in conjunction with the seven quality tools, are used to describe the current state of the business. The first two sections of this chapter (Overall Profitability and Graphical Analysis, respectively) are exploratory data analysis tools a small, low technology business owner might use to determine bottom-line performance in his or her firm. The Statistical Analysis section is aimed at the statistical methods portion of this study. Lastly, the Statistical Thinking Application section presents an alternative and commonly used method of viewing time-ordered data by the use of run charts.

Overall Profitability

A histogram of all forty[6] data points is shown in Figure 4 below. It appears skewed to the left with a mean profit margin of .022125 (2.2%).

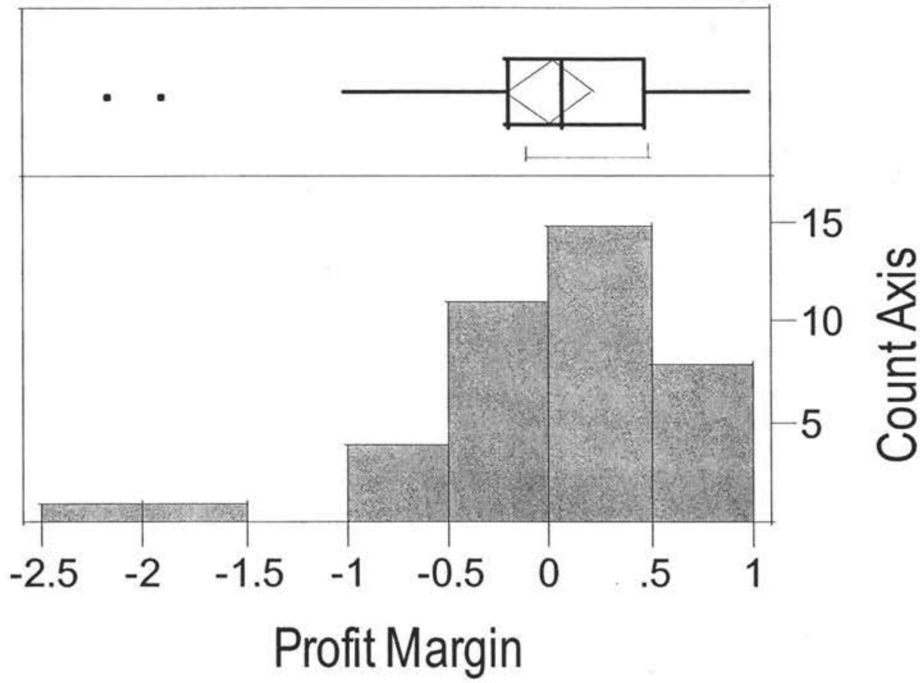


Figure 4. Overall Profit Margins

Stratification of the data into the various groups and treatments of interest allows for side-by-side comparison of various profit margin components. The following histograms are presented below:[7]

- Fabrication Profit Margins versus Installation Profit Margins (Type of Work)
- Sheet Metal Profit Margins versus Other Profit Margins (Scope of Work)
- Labor Profit Margins versus Material Profit Margins (Block)

Graphical Analysis

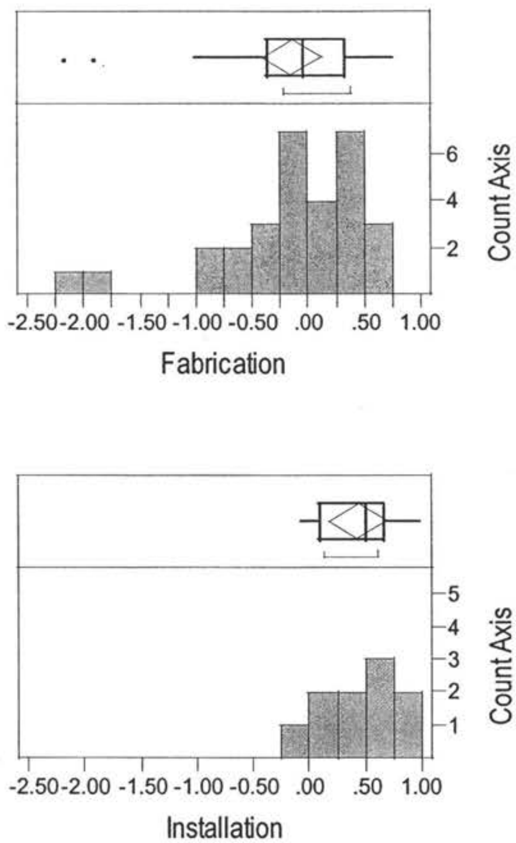
Exploratory data analysis performed on the following histograms is the statistical thinking application a business owner-manager may incorporate for a generally effective and

[7] Axis and increment settings in JMP stabilized for comparison purposes.

efficient overall assessment of business performance based on profit margins. They represent a method of thinking through what the data illustrate. The results of the graphical analysis may not reflect the results of the statistical analysis initially; however, it is at this impasse that statistical thinking plays a pivotal role in directing one's efforts to understand why there are differences (variation) in the two conclusions. If one begins with the premise that all work is a series of interconnected processes, clearly defining those processes, and subsequent outcomes, imparts an element of the owner or manager's practical experience into the knowledge base from which future decisions are made. Statistical thinking, therefore, becomes intermediary between knowledge and practical application. Consequently, graphical analysis may be the extent to which the "practical man" uses statistics until he or she obtains the practical benefits formal statistical methodologies achieve.

Fabrication versus Installation

Figure 5 below illustrates a clear indication of profit margin differences when comparing fabrication to installation in terms of combinatorial labor and material margins. The outliers uncovered in Figure 4 from -2.5% to -1.5% can now be attributed to at least one fabrication job. Furthermore, the low overall profit margin (approximately 2.2%) is due, in part, to the negative effects of fabrication jobs. In fact, the mean profit margin of fabrication jobs submitted in this study is -14.22%. In comparison to the installation margin (43.55%), there are seemingly substantial differences between these divisions of the company.



Mean	Std. dev.
-.1422	.6709

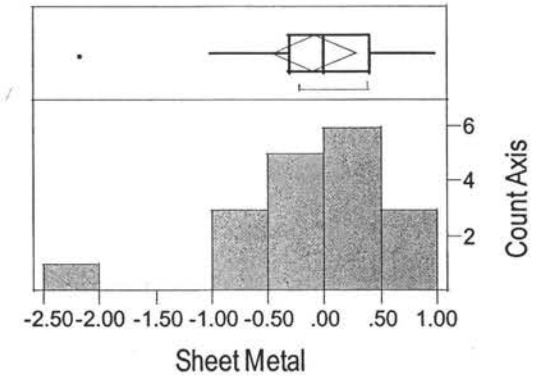
Mean	Std. dev.
.4355	.3389

Figure 5. Fabrication versus Installation

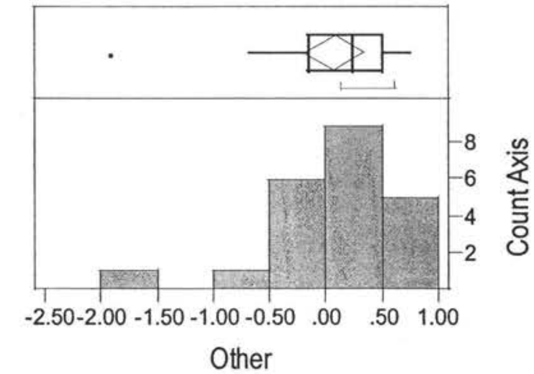
On average, contractual fabrication elements realize nearly a 200% increase in spread in comparison to similar elements in installation. Bearing in mind that the labor force is used cross-functionally throughout the company (a worker may work on a fabrication job in the shop one day but may then be called out for installation the next), it is somewhat surprising that there exists a dramatic difference in these standard deviations. However, the differences may be indicative of fundamental problems within the estimating process rather than the manufacturing process. It should also be noted that the overall profit margins may remain low due to the unbalanced nature of the analysis; that is, thirty fabrication points in comparison to ten installation points.

Sheet Metal versus Other

Figure 6 below stratifies the overall profit margin histogram to compare sheet metal jobs versus other jobs.



Mean	Std. dev.
-.0905	.7336



Mean	Std. dev.
.0781	.5840

Figure 6. Sheet Metal versus Other

Unlike the comparison between fabrication and installation, the histograms presented above are similar in both spread and level. Excluding the outliers of fabrication from the previous example, the histograms in Figure 6 are representative of what one may expect to find from the type of company in the study[8]. Again, there are more points within sheet metal (22) in comparison to other (18) that may inflate differences in mean profit margins between the two factors; however, these differences may be more representative of the type of work (fabrication/installation) rather than the scope of work. Graphically, one may conclude that the scope of the work performed, be it sheet metal, structural steel, piping, mechanical maintenance, or any other type of work the company may have contracted during the 2002 fiscal year, did not seem to directly impact the profit margins. This supports the previous observation that, fundamentally, the process of estimating should be evaluated for constancy of purpose for fabrication and installation. Based on similarities of these histograms, it is safe to conclude that the company should continue fabricating and installing cross-functional job types.[9]

Labor versus Material

In the study, profit margins were consequent of an estimated figure versus the actual cost of the component of interest; therefore, each job, whether it was fabrication or installation or whether it was sheet metal or other, resulted in two (2) profit margins:

1. Labor
2. Material

Figure 7 below aims to assess whether or not there are any apparent differences in mean profit margins and spread of labor versus material.

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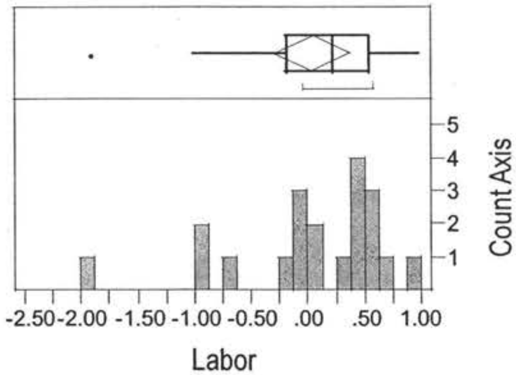
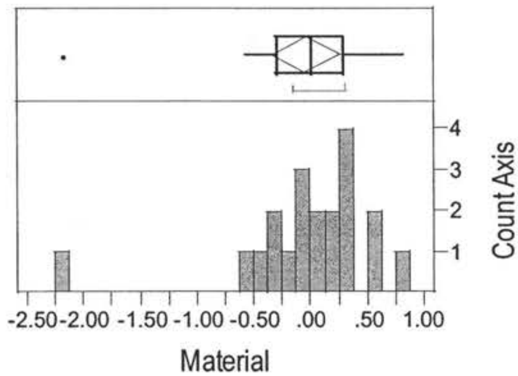
[8] In terms of similar margins within the same company with one person estimating all jobs.

[9] For the purpose of this study and lack of supportive data to the contrary, profit margin consistencies between all other job types (excluding sheet metal), are assumed equal.



Mean	Std. dev.
.0409	.6977



Mean	Std. dev.
-.0365	.6192

Figure 7. Labor versus Material

Interestingly, these histograms are different than both the first and second comparisons a priori. Although labor margins seem a bit more scattered, both appear to be skewed to the left. In terms of spread, these histograms demonstrate very little difference in both labor and material. However, the material mean is less than the labor mean, notwithstanding that this difference is the smallest of the three comparisons.

Similarly to Figure 6, Figure 7 shows the two (2) points falling below the -1.0 mark in both histograms further qualifying that this occurred at different levels of different factors and not just at one fabrication – type job for labor or material.

Statistical Analysis

Using JMP 5.0, statistical analysis was performed on the twenty contracted jobs at Mechanical Plus, Inc. Two (2) fabrication jobs were identified as outliers and removed from the formal statistical analysis. A factor profile was generated and compared to the histograms presented above. One finds consistent similarities in terms of differences between Fabrication/Installation, Sheet Metal/Other, and Labor/Material, respectively, illustrated in the histograms above.

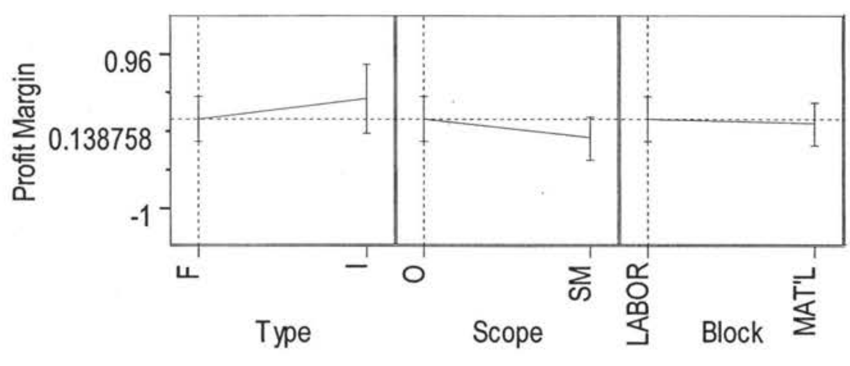


Figure 8. Factor Profiles

Results

The Split-Plot/Repeated Measures output is shown in Table 5 below. A p-value of .05 or below recognizes significant factor differences.

Table 5.

JMP 5.0 ANOVA Table

Source	DF	Sum of Squares	F Ratio	Prob > F
Type	1	1.61405	9.0662	0.0051
Scope	1	0.00001	0.0001	0.9935
Type*Scope	1	0.43224	2.4280	0.1290
Block[Type]&Random	2	0.06994	0.1965	0.8226
Error	32	5.69695		
Total	37	7.81319		

From the analysis of variance table above, only Type (fabrication versus installation) is statistically significant with an F Ratio of 9.0662 and a p-value of 0.0051. Even though there appears to be significant interaction in the interaction profile (see Figure 9), the interaction is not significant with an F Ratio of 2.4280 and a p-value of 0.1290.

This analysis confirms the conclusion of the graphical analysis of Figure 5 that fabrication and installation are significantly different. Scope (Sheet Metal versus Other) was not found to be statistically significant nor was the interaction of Type*Scope found to be statistically significant.

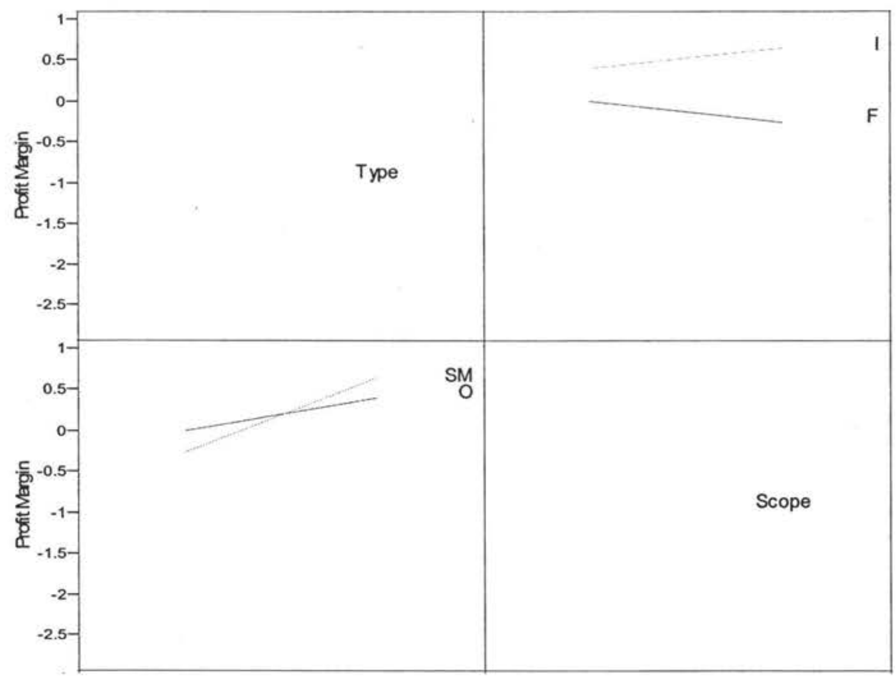


Figure 9. Interaction Profile

Tests of Hypothesis

Research Question 1

Is there a significant difference in mean profit margins between contracted fabricated jobs and contracted field installation jobs?

Null Hypothesis 1

There is no significant difference in mean profit margins at the $\alpha = .05$ level between fabrication jobs and installation jobs.

Statistical Hypothesis 1

$$Ho: \mu_{fab} = \mu_{Instal}$$

$$Ha: \mu_{fab} \neq \mu_{Instal}$$

Conclusion

Reject Null Hypothesis 1 at the .05 a level. The study indicates significant differences between fabrication jobs and installation jobs.

Research Question 2

Is there a significant difference in mean profit margins between sheet metal jobs and other jobs?

Null Hypothesis 2

There is no significant difference in mean profit margins at the $\alpha = .05$ level between the sheet metal jobs and other jobs.

Statistical Hypothesis 2

$Ho : \mu_{SheetMetal} = \mu_{Other}$

$Ha : \mu_{SheetMetal} \neq \mu_{Other}$

Conclusion

Fail to reject Null Hypothesis 2 at the .05 a level. The study did not indicate significant differences between sheet metal jobs and other jobs.

Research Question 3

Is there any significant interaction between type of job (fabrication/installation) and scope of job (sheet metal/other)?

Null Hypothesis 3

There is no significant interaction between the different levels of job type and job scope.

Statistical Hypothesis 3

$$Ho: \mu_{Fabrication*SheetMetal} = \mu_{Fabrication*Other} = \mu_{Installation*SheetMetal} = \mu_{Installation*Other}$$

$$Ha: \mu_{Fabrication*SheetMetal} \neq \mu_{Fabrication*Other} \neq \mu_{Installation*Sheetmetal} \neq \mu_{Installation*Other}$$

Conclusion

Fail to reject Null Hypothesis 3 at the .05 a level. The study did not indicate significant interaction between different levels of job type and job scope.

Statistical Thinking Application

Small, low technology firms may not have the resources, or personnel with the requisite knowledge to perform statistical analyses based on experimental designs. For owners and/or managers, the histograms presented at the beginning of this chapter may, in many ways, afford themselves to the objectives of a small firm. An additional tool discussed in Chapter 2 of this study is run charts. Commonly used in manufacturing, these charts represent a time-order of the process at hand. Figure 10 illustrates examples of two (2) moving range charts[10] used as an additional method for recognizing performance issues in processes. These run charts do not exclude the outliers. Similar to the histograms comparing fabrication and installation, the Moving Range Charts demonstrate the following:

1. Overall spread in fabrication jobs is almost two times that of installation jobs.
2. The mean profit margins are substantially greater for installation than fabrication.

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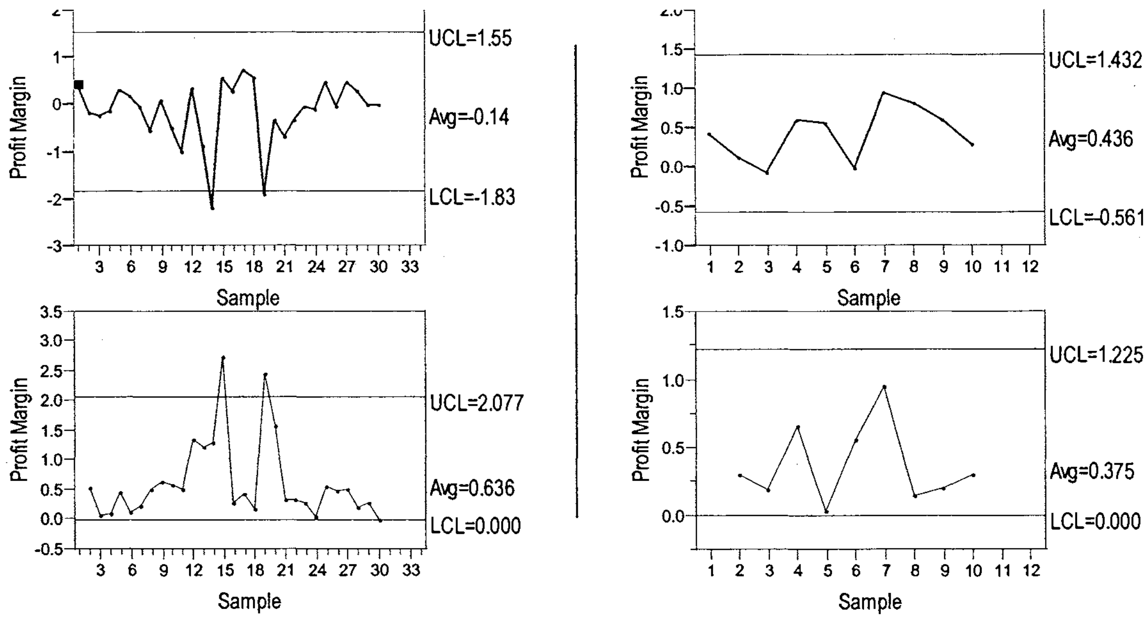
[10] Moving Range Charts are run charts that are used when having subgroups of 4 or more data points is difficult due to lack of data. Moving Range Charts have two points with each subsequent subgroup reusing 1 data point.



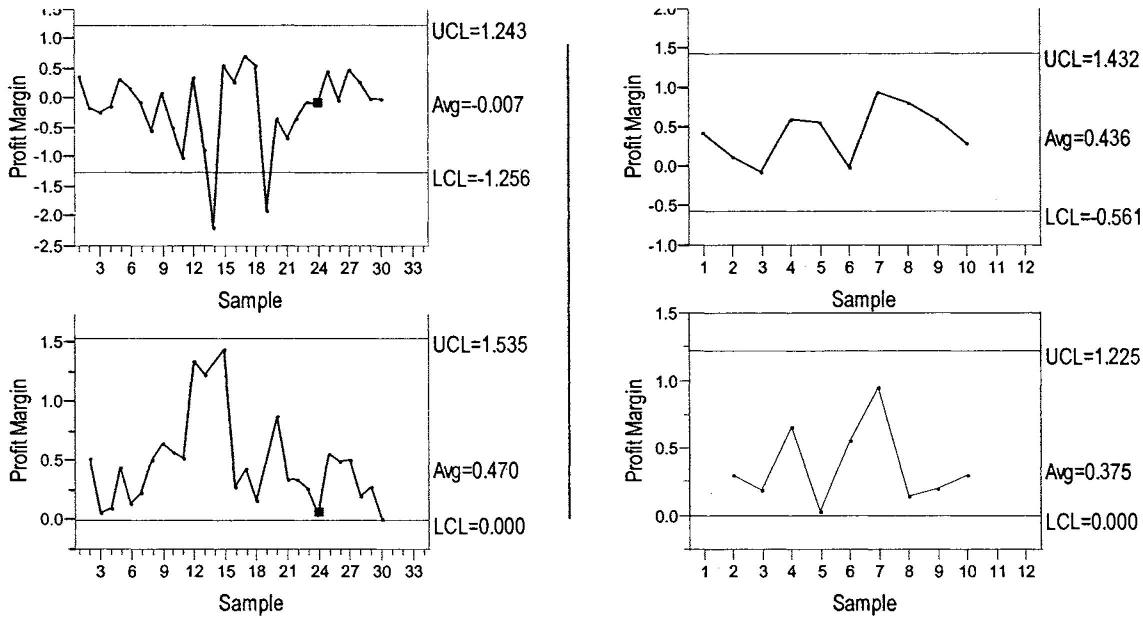
Fabrication Moving Range Chart

Installation Moving Range Chart

Figure 10. Moving Range Chart

In the charts, "UCL" and "LCL" are acronyms for Upper Control Limits and Lower Control Limits, respectively. These limits, derived using coefficients based on the number in the sample size, demonstrate how the process performs with the current subgroup ranges (within subgroup variation). Points falling outside the control limits are viewed as abnormally large or small within the context of the current process. In light of the large variation within both fabrication and installation, very large control limits are calculated. In terms of fabrication, based on the profit margins of this study, it is reasonable to predict that if the current process remains unchanged, one might expect profit margins of both material and labor to fall somewhere within -1.83 (-183%) to 1.55 (155%). From a practical standpoint, these are unacceptable margins, particularly when estimation aims to predict actual costs at twenty percent margins with a desirable margin of error at ± five percent.

Moving Range Charts with Outliers Removed



Fabrication Moving Range Chart with outliers removed

Installation Moving Range Chart

Figure 11. Moving Range Chart without Outliers

After removing the outliers from the calculations of the UCL and LCL in fabrication, the average range drops from .636 to .470 (Figure 11). Likewise, the mean profit margins increase from -.14 with outliers to -.007 without the outliers. Note that the average range decreased as well resulting in tighter control limits. In both cases, with and without outliers, there is no apparent time trend in the moving range charts.

Summary

The results of the statistical analysis indicated that there are significant differences between Type of work (fabrication and installation). There is, however, no statistically significant effect of Scope of work nor is there any significant interaction between Type and Scope. The null hypothesis was rejected for Type but it failed to be rejected for Scope and the interaction term. It was found that large variations exist overall. Of particular interest are the histogram comparisons (including outliers) of fabrication versus installation (Figure 5) showing seemingly clear indicators that fabrication, on average, results in lower profit margins at almost twice the spread level. To this end, a cause and effect diagram was developed to identify sources of variation in fabrication profit margin. It can be found in Appendix C. Considering a variety of potential causes, as listed on the diagram, the researcher hopes to improve the overall efficiency of the estimating process at hand.

CHAPTER 5. SUMMARY, CONCLUSION, AND RECOMMENDATIONS

Summary

Statistical thinking is a forward-looking mentality always aiming to improve the process by reducing unwanted and wasteful variation. Small, low technology firms often lack the necessary human and informational resources by which to assess variation in their business. This study presented a methodology of performance measurement based on profit margins that is utilized in a small firm. The literature points to the advantage of reducing variation to increase profitability. In this study, variation in the estimation process was a key element in variability of profit margin. In particular, a small number of outliers in job type (Fabrication/Installation), contributed to the inability of an ANOVA to determine statistically significant differences between factors. Once the outliers are removed, a statistically significant difference was observed in job type. These outliers are special cause variation that must be addressed but are beyond the scope of this research. However, graphical representation points to key areas of improvement needs. Notably, the Moving Range Chart presented at the end of Chapter 4 exemplifies the effects of large within factor variation: inflated control limits.

Research Questions

Overall, only type of job was found to be statistically significant in terms of the research questions posed in the first chapter of this study.

- The contribution to profit margin of fabrication was found to be statistically significantly different from the contribution that could be traced to the installation.

- The contribution to profit margin of sheet metal work was not found to be statistically significantly different from the contribution that could be traced to other scopes of work.
- There was insufficient evidence to suggest significant interaction at different levels of type of work and scope of work.

Conclusion

This study concluded that there is evidence to support that type of work, in terms of profit margins, differs at Mechanical Plus, Inc. Namely that fabrication jobs diminish the overall profits of the company. However, the study may have enabled an even greater benefit by exposing an underlying deficiency of variation control throughout the estimating process. Furthermore, the use of statistical tools, both statistical thinking and statistical methods, were used in the development and subsequent analysis of the study. This reiterates Balestracci's (2002) view that statistical thinking adds to the knowledge base from which to ask the right questions. The study began with three questions of type of work, scope of work, and interaction, and ended with one important and key question in the potential growth and profitability of Mechanical Plus, Inc.: Why so much variation from estimated to actual profit margins?

As a direct result of this research, data is now collected on both job size (in terms of dollar value) and weight (lbs.) of raw steel. Before the estimated process can be evaluated further, the researcher will gather more data and evaluate actual job costs and their relationship to dollar value and weight. Essentially, when enough data is collected, the researcher intends to use weight of the raw steel and the actual cost of jobs (as they are now estimated) to study whether there exists a linear regression trend. Notwithstanding differing complexities of jobs, a coefficient of weight-to-price will be developed as a new standard estimating tool. This, in turn, will realize better estimation of fabrication jobs, higher throughput of estimates, and, ultimately, a higher profit margin.

Statistical Thinking Application

The third purpose of this study was described in Chapter 1:

> To incorporate statistical thinking into performance measurements for small manufacturing firms as set forth by Britz, Emerling, Hare, Hoerl, and Shade (1996):

One of the most valuable assets that can be taken from this study is the process by which the data was collected, viewed, analyzed (graphically), and future areas of improvement identified. It is essentially Deming's cycle of P-D-S-A or Plan, Do, Study, Act. In this research, Plan, Do, and Study elements were categorically accomplished. The next step is Act. By incorporating new measurement devices in the estimating process to track costs and other pertinent information, one continues the cycle by:

- **Planning** the next study.
- **Doing** the next study.
- **Studying** the results.
- **Acting** again for further improvements.

RECOMMENDATIONS

The results of the study provide some solid ground work from which future studies may abound. For the interim, all fabrication jobs have ten to twenty percent margins added to the overall cost of the job, depending on the competitive nature of the job. Estimation of installation jobs, by and large, will not be manipulated in any form due, in part, to the following factors:

1. The study resulted in less variation in installation jobs versus fabrication jobs.
2. The researcher is the Production and Operations Manager at Mechanical Plus, Inc. and his chief responsibility is managing fabrication.

The study concluded that a wide range of variation throughout the types and scopes of work exist. Future research in this area should target fabrication. Using the cause and effect diagram, it was surmised that the estimator's method of estimating (Secondary Cause of Estimator: Estimation Appropriateness) may contribute to the variation in fabrication jobs. Estimation Appropriateness refers to how the estimator conceptualizes the differences from fabrication to installation and its effect on how jobs are estimated. Via direct daily contact with the estimator, the researcher finds that the estimator views the process of fabrication estimation similar to installation estimation. Consequently, fabrication differs from installation in terms of process and should, therefore, be viewed quite differently in terms of job estimation. Future studies may identify some of those differences. Specifically, a two-fold study analyzing (1) the efficiency of using weight-to-price fabrication cost coefficients, and (2) the variation of estimated versus actual fabrication jobs using the weight-to-price cost coefficient and how it compares to the variation in this study.

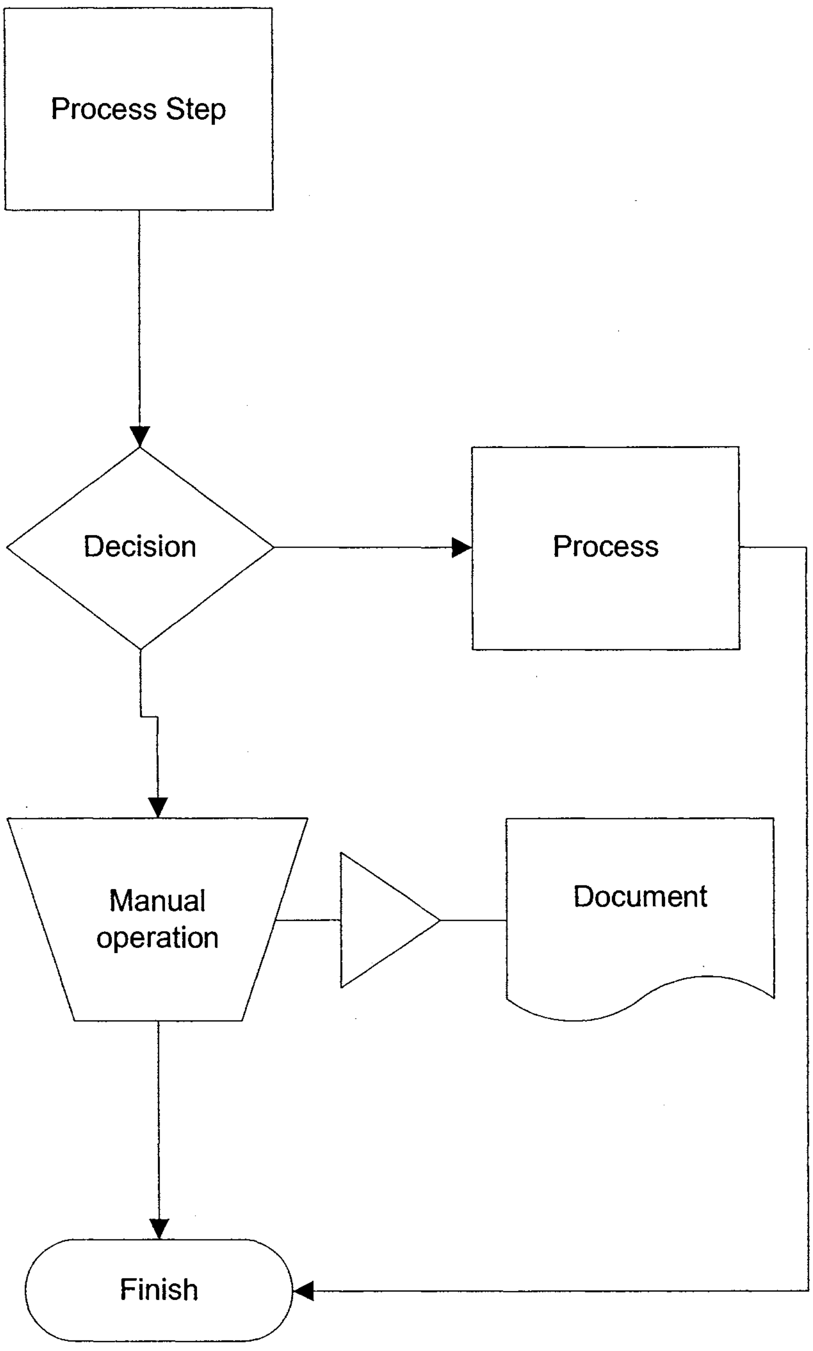
APPENDIX A: JOB COST ANALYSIS

Job Cost Analysis

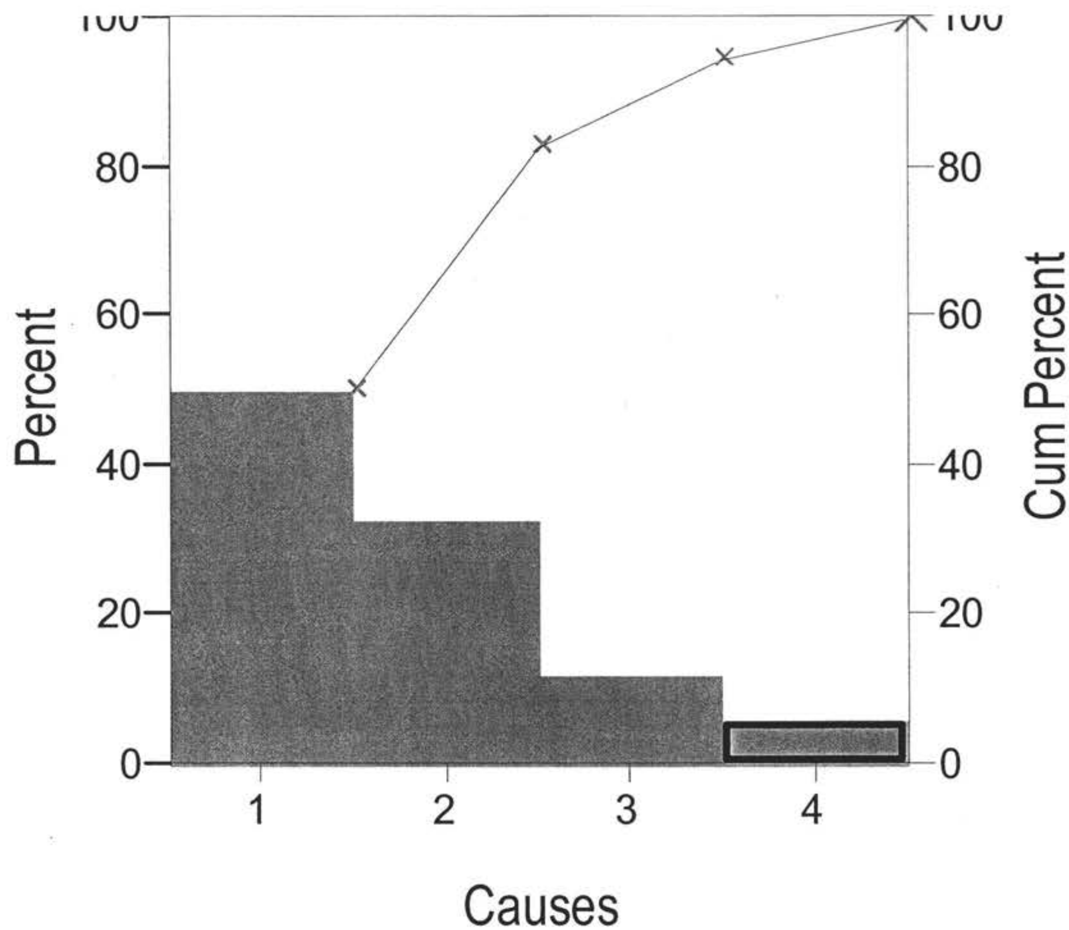
	Job Number	Customer	JOB TYPE	JOB SCOPE	ESTIMATED LABOR HOURS	ACTUAL LABOR HOURS	DIFFERENCE - PROFIT GAINS/LOSSES	ESTIMATED MATERIAL COST	ACTUAL MATERIAL COST	DIFFERENCE OR PROFIT
1	0	0				0.00	$0.00			$0.00
2	0	0				0.00	$0.00			$0.00
3	0	0				0.00	$0.00			$0.00
4	0	0				0.00	$0.00			$0.00
5	0	0				0.00	$0.00			$0.00

APPENDIX B: SEVEN QUALITY TOOLS

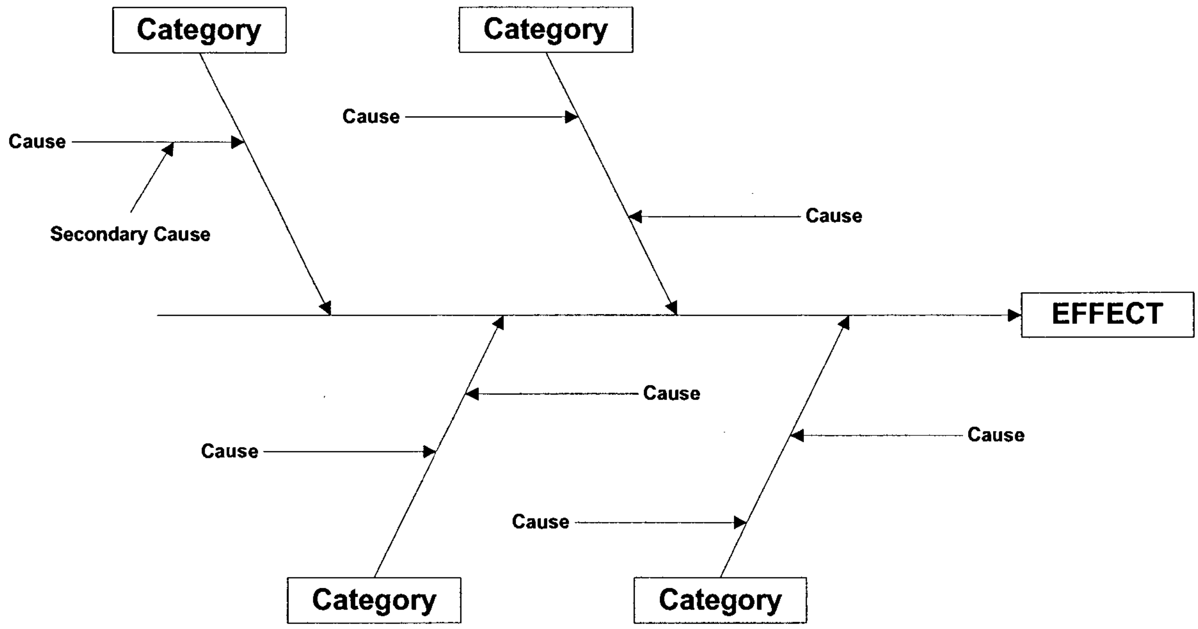
Flow Chart Example



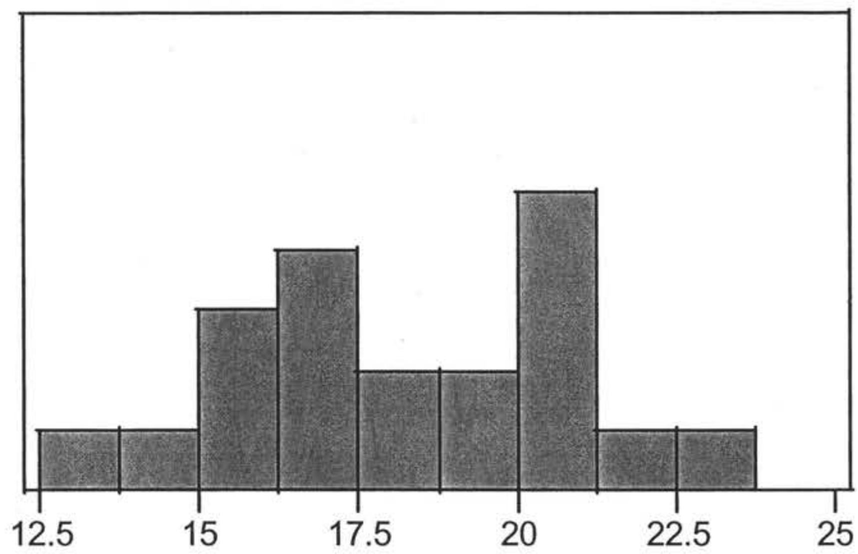
Pareto Chart Example



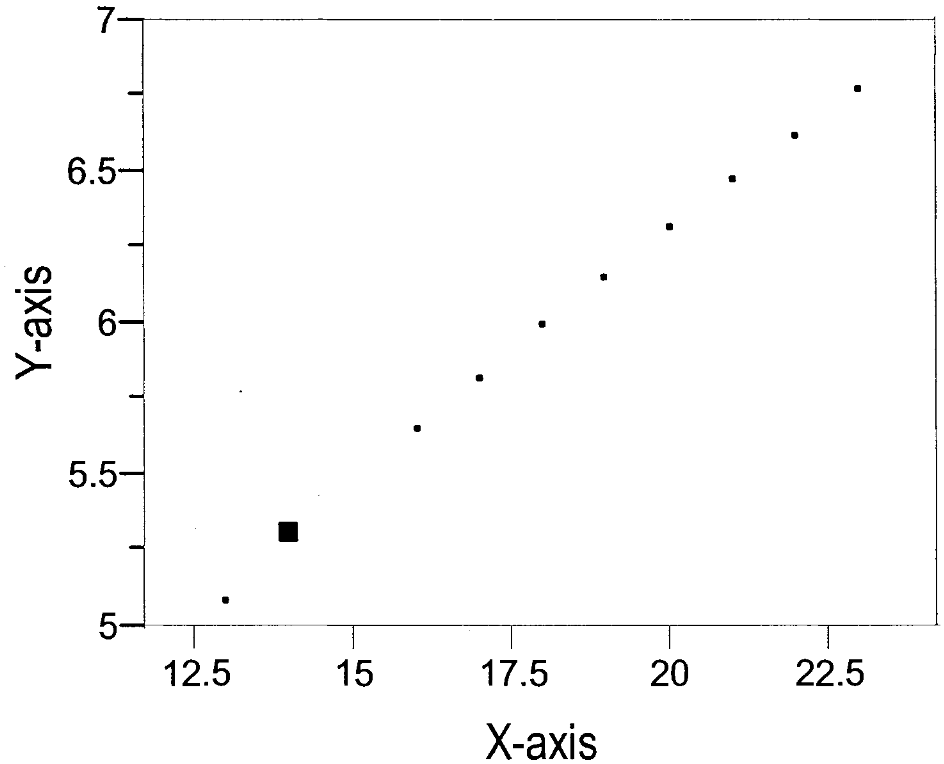
Cause and Effect Diagram Example



Histogram Example



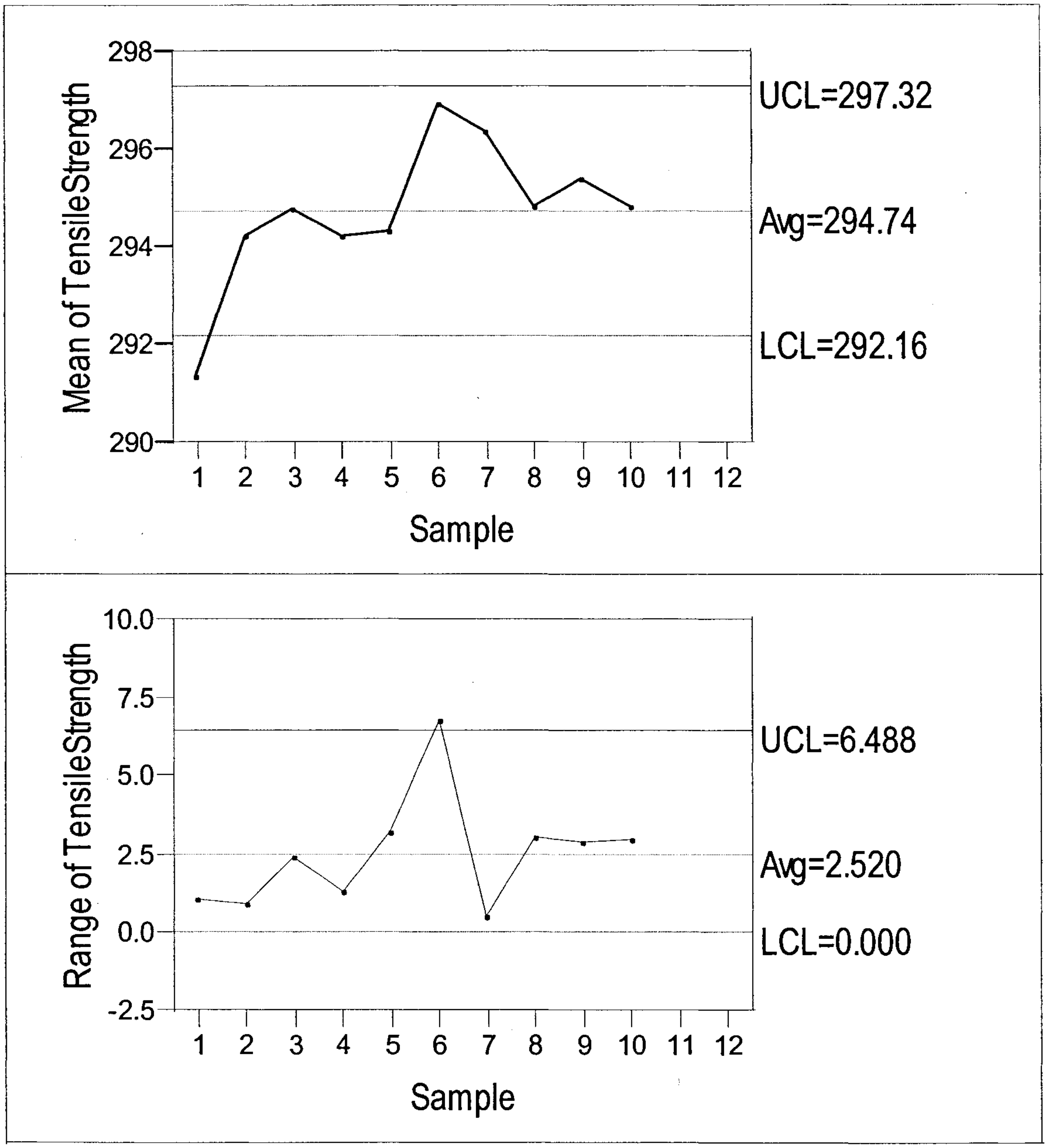
Scatter Diagram Example



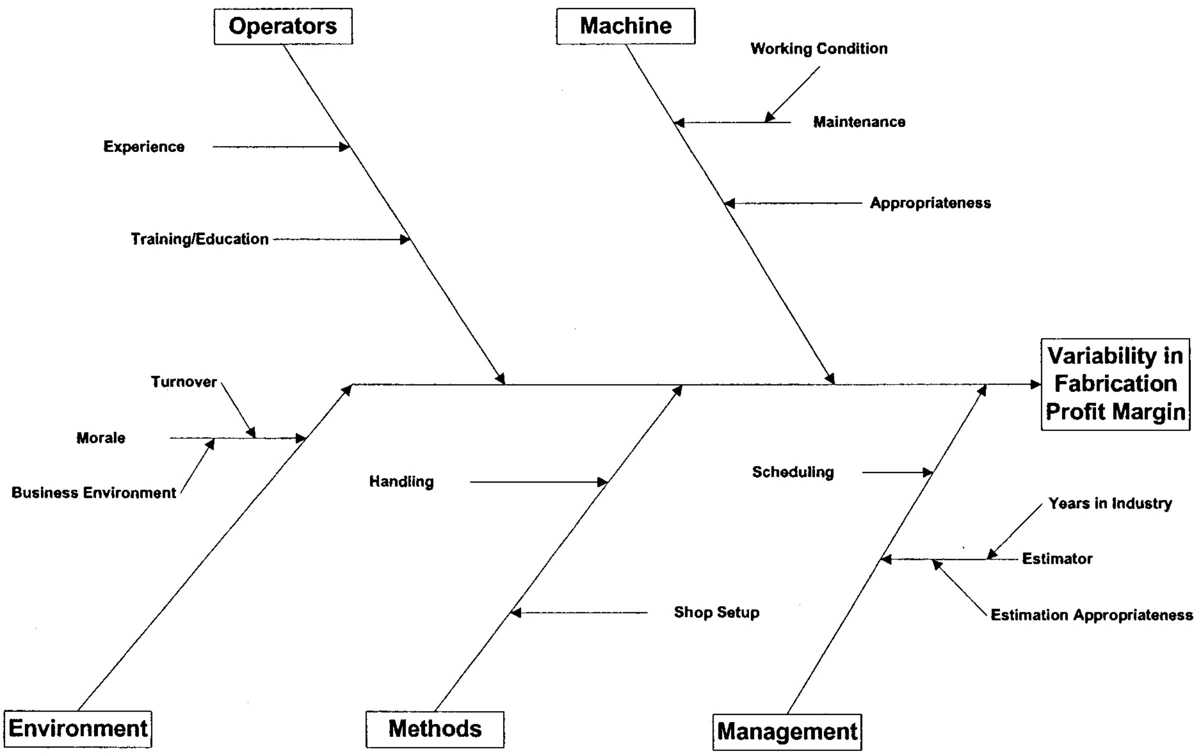
Check Sheet Example

	Objective 1	Objective 2	Objective 3	Objective 4
Quality Issue				
Quality Issue				
Quality Issue				

Run Chart Example



APPENDIX C: CAUSE AND EFFECT DIAGRAM



Operators
Machine
Working Condition
Maintenance
Experience
Appropriateness
Training/Education
Variability in Fabrication Profit Margin
Turnover
Morale
Business Environment
Handling
Scheduling
Years in Industry
Estimator
Estimation Appropriateness
Shop Setup
Environment
Methods
Management

REFERENCES CITED

1. American Society for Quality. (July, 2002) Quality Glossary. Retrieved March 30, 2003, from http://www.asq.org/info/glossary/index.html.

2. Balestracci, D. (Summer, 1998). Data "Sanity": statistical thinking applied to everyday data [Special Publication]. Statistics Division American Society for Quality.

3. Bigelow, M. (2002). How to achieve operational excellence. *Quality Progress*, 35(10), 70-75.

4. Britz, G., Emerling, D., Hare, L., Hoerl, L., & Shade, J. (Spring, 1996). Statistical thinking [Special Publication]. Statistics Division American Society for Quality Control.

5. Deming, W. E. (1986). Out of the Crisis. Cambridge, MA: Massachusetts Institute of Technology, Center for Advanced Engineering Study.

6. DeVor, R. E., Chang, T., & Sutherland, J. W. (1992). Statistical quality design and control: contemporary concepts and methods. Upper Saddle River, NJ: Prentice-Hall, Inc.

7. Dhawan, R. (2001). Firm size and productivity differential: theory and evidence from a panel of US firms. *Journal of Economic Behavior & Organization*, 44, 269-293.

8. Groth, J. C., & Kinney, M. R. (1994). Cost management and value creation. *Management Decision*, 32(4), 52-57.

9. Hansen, P. A., & Serin, G. (1997). Will low technology products disappear? The hidden innovation processes in low technology industries. *Technological Forecasting and Social Change*, 55, 179-191.

10. Jayaraman, V., & Srivastava, R. (1996). Expert systems in production and operations management. *International Journal of Operations & Productions Management*, 16(12), 27-44.

11. Latino, R. J., & Latino, K. C. (2002). Root cause analysis: improving performance for bottom line results (2nd Ed.). Boca Raton, Fl: CRC Press LLC.

12. Laverty, K. J. (2001). Market share, profits and business strategy. *Management Decision*, 39(8), 607-617.

13. Leitnaker, M. G. (Summer, 2000). Using the power of statistical thinking [Special Publication]. Statistics Division Statistics Division American Society for Quality.

14. Nave, D. (2002) How to compare six sigma, lean thinking and the theory of constraints. *Quality Progress*. Retrieved September 8, 2002, from http://www.asqnet.org/members/news/qualityprogress/2002/0302/73howTo.html.

15. Nelson, L. S. (1985). Sample Size Tables for Analysis of Variance. *Journal of Quality Technology*, 17(3), 168-169.

16. Okes, D. (2002) Organize Your Quality Tool Belt. Retrieved March 30, 2003, from http://www.asqnet.org/members/news/qualityprogress/2002/0702/25organi0702.html [2003, March 29].

17. Reid, G. C. (1999). Complex actions and simple outcomes: how new entrepreneurs stay in business. *Small Business Economics*, 13, 303-315.

18. Roper, S. (1999). Modeling small business growth and profitability. *Small Business Economics*, (13), 235-252.

19. Small Business Administration - Office of Advocacy. (2003) Small Business by the Numbers. Retrieved April 13, 2003, from http://www.sba.gov/advo/ Stats/ sbfaq.pdf.

20. Society of Manufacturing Engineers/Association for Forming & Fabricating Technologies. (2002). Lack of long-term R&D costly for manufacturers. 15.

21. Sterlacchini, A. (1999). Do innovative activities matter to small firms in non-R & D-intensive industries? An application to export performance. *Research Policy*, 28, 819-832.

22. Tornatzky, L. G., Batts, Y., McCrea, N. E., Lewis, M. S., & Quittman, L. M. (1996). The Art & Craft of Technology Business Incubation. Southern Technology Council National Business Incubation Association.

23. Townsend, P., & Gebhardt, J. (2002). Simple Quality for Smaller Organizations. *Quality Progress*, 35(10), 76-80.

24. Waurzyniak, P. (2002). Software for job shops. *Manufacturing Engineering*, 47-54.