Field Study of the 5-Axis Forest-Line versus the 5-Axis Fidia-211

In the Case of a Midwestern Engineering Firm.

by

Jeffrey Bushendorf

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Danny J. Bee

The Graduate School

University of Wisconsin-Stout

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The Graduate School
University of Wisconsin-Stout
Menomonie, WI

Author: **Bushendorf, Jeffrey D**

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ABSTRACT

Using my experience as a Manufacturing Engineer at an engineering company in New Brighton, Minnesota, my Master's Thesis came as an answer to many questions surrounding the company's choice to replace the 5-Axis Forest-Liné milling center with the 5-Axis Fidia-211 milling center. The engineering firm made that choice after an energy audit by a private corporation suggested that the Forest-Liné was outdated and costing the company more money to run than a newer, more energy-efficient model. The purpose of this field problem was to determine if this suggestion was valid, and to determine if the newer model is saving the company money. In short, is the Fidia-211 more energy-efficient and cost-efficient than its predecessor, the Forest-Liné?

Through analysis of business utility statements, signed and approved shop floor logs, and brochures from each of the machine's manufacturers, the data proved the 5-Axis Fidia-211 to be a

far more energy-efficient and cost-efficient choice for the Midwestern engineering firm. With this conclusion, I was able to present management with concrete evidence that their choice to replace the Forest-Liné was completely warranted, and is currently saving them money due to the efficiencies the Fidia-211 offers.

Acknowledgments

It is a pleasure to thank the many people who made this thesis possible. This thesis grew out of a series of conversations with my coworkers at the engineering firm at which I am currently employed. Each one of them offered insights and ideas that were immensely helpful in the conceptualization process. From the initial concept to the final conclusion, peers at my company were eager and willing to assist in any way possible. I would like to thank them for their constant support and generosity of thought. Quite importantly, I wish to gratefully acknowledge the enthusiastic supervision of Danny J. Bee. I have heard horror stories of terrified graduate students complaining about their thesis supervisors, and I can honestly say I cannot imagine a better match for me during this entire process. His constructive and enlightened criticism helped mold this project into something I can truly be proud of. Without his supervision, I wouldn't have had the experience that I am now so grateful for. I would also like to thank my wife, who encouraged me endlessly throughout this entire master's program. Her eager, editing eyes were always willing to assist me with assignments and to help with proper human phrasing in times when my engineering psyche wanted to be assuming and short. I also wish to thank my supportive family for all their encouragement and understanding during stressful times. I want to also express my gratitude to the University of Wisconsin-Stout for offering a graduate program that fit perfectly into my life. The staff has been more than helpful in assisting me with any needs I had along the way. Without the versatility that this distance learning graduate program offers, I would not have been able to pursue my degree. I accredit my success in this program to the program itself.

TABLE OF CONTENTS

Chapter I: Introduction

Statement of the Problem

Over twenty years ago, a small Italian machining company broke ground in Michigan to erect a building that would be their proud flagship in the North American hemisphere (Morfino, 2007). This company, Fidia, Inc., has since spent the past two decades filling numerous customer orders for a plethora of machining tools. They are world-renown for their milling systems, specializing in specific components to meet each customer's needs.

About ten years ago, an even smaller engineering company was in the market for a new milling system for their machine shop floor. The engineering firm, a Minnesota-based industry leader in aerospace, design, and contract manufacturing, purchased a 5-Axis Forest-Liné machine from one of Fidia's fiercest competitors, Forest-Liné. The 5-Axis Forest-Liné machine is comparable to a Fidia machine of the same class, except for the price tag. The Forest-Liné machine comes in at about eleven-thousand dollars less than a similar Fidia machine (Chabrais, 2004). The Midwestern engineering firm chose the financial savings of Forest-Liné and made room for the extremely large milling center in their shop by demolishing an outdated storage area. The demolition was quickly finished, and the machine was installed in January of 2004.

Time passed quickly since the aforementioned installation was completed. Today, the value of the dollar is diminishing, and the economy is on very unstable ground. With all this uncertainty, Americans are trying to focus their energy on problems they believe they can solve. One problem in particular is that of global climate change. Everywhere one looks, marketing and advertising is telling humankind to go "green". Coffee shops are providing their hot beverages in biodegradable cups. Department and grocery stores alike are offering discounts to customers who

bring their own reusable bags for shopping. People are purchasing recyclable wrapping paper for gifts, opting for fabrics instead of metallic, glittery foils. Colleges and Universities are even offering degrees in fields such as sustainable futures. "Green" is hardly a new concept, but new legislation and the growing demand for more earth-friendly products and more-importantly, more earth-friendly manufacturing processes, is driving engineering companies to audit their perspectives on current engineering practices.

The engineering company was no exception to the rule. In 2008, a private corporation performed an energy analysis on the company's plant in New Brighton, Minnesota. The analysis showed a vast amount of energy consumption and waste in the facility. Recommendations were made for certain areas of the plant to conserve energy and cut back on costs. One such recommendation was for the company to replace the 5-Axis Forest Liné milling center with a more energy-efficient model. After careful consideration, the firm decided it was in the company's best interest to purchase a 5-Axis Fidia-211 machine. The Fidia machine boasts a strong advantage over competing milling centers with a thirty-five percent energy savings claim in the span of five years over the previous model. That same model was the one up against the Forest-Liné machine in 2004 when the company was choosing price as its determining factor for purchase.

With all the world's attention on global climate change, and that attention causing engineering companies of all sizes to assess their energy consumption, it begs the question if the Midwestern engineering firm made the right choice in replacing it's power-hungry Forest-Liné machine with the Fidia-211. Is the cost of new technology worth the energy savings, or would the engineering firm have been better off keeping their previous 5-Axis Forest Liné?

Purpose of the Study

The purpose of the study was to make an intricate comparison between the 2004 Forest

Liné model and the 2008 Fidia-211 model to determine the true energy cost, performance and machine cost, as well as environmental and intrinsic worker improvement cost to create a whole picture that would recommend one machine over the other for the engineering firm. Data will be compiled into two separate classifications of time. Information regarding February 2004 to February 2005 will be collected for the 5-Axis Forest Liné, and July 2008 to July of 2009 information will be collected for the 5-Axis Fidia-211. These separate twelve month time spans for each respective machine will be compared to one another to definitively conclude which unit, for the dollar, was more cost-efficient and energy-efficient. Therefore, this study will benefit the engineering firm by supporting either the switch from Forest-Liné to Fidia, or negating the necessity of new Fidia technology due to the cost. Would the company have been better off fiscally with their 5-Axis Forest-Liné? Is the extra cost really saving them energy? In layperson terms, is a newer [more energy efficient machine] really better?

Assumptions of the Study

The study will assume that the engineering firm consistently went through Xcel Energy, Inc. for business class utility service. The study will also assume that the engineering firm consistently paid utility bills in a timely fashion, assuring no extra charges were assessed due to late fees or other payment indiscretions. It will be assumed that all records derived from accounting practices are accurate and void of discrepancy.

Definition of Terms

Green Engineering. The design, commercialization, and use of processes and products, which are feasible and economical while minimizing 1) generation of pollution at the source and 2) risks to human health and the environment. (EPA)

Traditional Engineering. Engineering based upon traditional materials without concerns of recycling, biohazards, and environmental focus.

Global Climate Change. Also known as the "greenhouse effect", this term refers to major climate shifts due to the high levels of greenhouse gases. These gasses are largely from the consumption of fossil fuels. The term also is used in relation to human interaction. Popular belief is that humans can lessen the impact of global climate change by improving their habits of recycling, reducing energy consumption, and reducing emissions.

KwH. Kilowatt Hours.

kVa. Kilovolt-Amperes.

kWs. Kilowatts.

Spindle. The electronic motor that rotates the tool within the machine.

Limitations of the Study

The study will only include data from February of 2004-Febraury 2005, and data from July 2008-July 2009. The study will not account for economic inflation. The study will determine a cost for repairs and maintenance to be used in the comparison between both machines.

Methodology

Data will be compiled from the New Brighton plant and reviewed. Only data from the designated time spans will be assessed. Cost will be broken down for each day, month, and year in each designated time span. That cost will include the electricity to power both the 5-Axis Forest-Liné and the 5-Axis Fidia-211 for each month during the study. After the financial aspect of

the electricity cost is concluded, that cost will be assessed in comparison to the overall cost of each machine. A conclusion will then be drawn to determine whether the additional price of the Fidia-211 is worth the supposed energy savings, or if the less-expensive Forest-Liné milling center comes out to be more economical in the long run for the Midwestern engineering firm.

Chapter II: Literature Review

Changes in How Conservation is Viewed

A simple flip of the switch on any television channel will flood you with two separate types of commercials. The first is "the bad economy" commercial type, and generally immerses viewers in pictures of The Great Depression, followed by pictures of dollar signs fading away into the distance. The second type is the "green" commercial. These commercials remind viewers that since the economy is so uncertain, they should be spending their hard-earned dollars on green products, because green products have the benefit of bettering the earth. Green commercials also have the benefit of telling people what they can do in the form of actions to succeed in this betterment. Shut off those lights! Or, at the very least, buy energy-conserving light bulbs. Unplug that computer! Or, at the very least, buy an energy-efficient surge protector to save power. Businesses stood on the fence for quite some time while individuals were targeted by this brand of commercialism. In the last five years, however, that has begun to change.

Frito-Lay North America, Inc., the makers of Sun Chips, is one such example of change. The company unveiled a brand-new ad campaign recently regarding their packaging. Sun Chips® brand went from traditional packaging to packaging that consists of 33% renewable plant-based materials (Zimmer, 2008). After those commercials attracted green consumers, Frito-Lay decided to publicize their energy-conserving business practices at their production plant in Modesto,

California. In 2008, a solar collector field was installed on four acres of the Modesto location's property. The National Renewable Energy Laboratory deemed it sound, and approved Frito-Lay to begin powering the facility by the captured rays of the sun. This is one of many production plants, and companies in general, that are changing the way conservation is viewed in a business setting. Frito-Lay's successful ad campaign proves that consumers support energy-conservation in factories and manufacturing facilities just as importantly as they support individual energy-conservation.

What is known?

People have been comparing and scrutinizing energy-conserving products for years. Are they better than previous models with no conservation focus? Do they really save money in the long run? Are appliances with a conservation focus more expensive to fix? One of the most influential forces in the United States today makes it a priority to answer questions such as these. The US Environmental Protection Agency (EPA) started the Energy Star program as a joint venture with the US Department of Energy. The program states "a strategic approach to energy management can produce twice the savings - for the bottom line and the environment - as typical approaches" (US Department of Energy, 2007). Since its inception in 1992, Energy Star has been offering businesses unbiased information on products and services that make energy conservation a simple choice. More than 2,400 organizations and businesses have joined the Energy Star program to date. They boast that with their program, businesses can improve the efficiency of their buildings, including machinery, by ten percent. For example, a case study made public by the Energy Star program shows solid proof that replacing outdated machinery with newer, energy-efficient models, was able to save one organization from embarrassment and unwarranted costs.

The San Diego Crime Lab in California was in dire need of some upgrades. Their 18 year old chiller plant was using two extremely outdated 130-ton air-cooled reciprocating chillers. This was costing the lab in terms of demand charges and waste of energy. On top of those problems, the city had plans for expanding the laboratory which meant more cooling capacity would be required. One option was to replace the reciprocating compressors with air-cooled screw compressors. According to a plant-wide energy audit and analysis, a retrofit would supply the needed capacity—but with only moderate energy and demand savings. After further deliberation and evaluation of the existing equipment and the facility's needs, the city opted instead for the installation of an all-variable-speed water-cooled chiller plant. This included variable-speed cooling tower fans and pumps on both the chilled- and condenser-water side, as well as a magnetic-bearing compressor that could operate at variable speeds (U.S. Department of Energy, 2009).

The new chiller plant, including the pumps and fans, performed at an average efficiency of 0.538 kilowatts (kW) per ton. Traditionally, a plant efficiency of 0.7 to 0.8 kW/ton is considered good in the under-300-ton size range, and most plants operate at 1.0 kW/ton or above. The old air-cooled chiller plant was measured as using around 1.48 kW/ton. The incremental cost and savings between a new standard chiller plant (using air-cooled screw compressors without variable-speed equipment) and the all-variable plant produced a payback of five years based on energy and demand savings alone. Incentives provided by San Diego Gas & Electric further reduced the incremental payback to two years. The ongoing estimated annual energy and demand savings amount to about $65,000.

This case study is proof that one company benefited from enacting a conservative energy focus. The Energy Star program has multiple case studies available with the same general results.

Does that mean it is true for every company? With companies everywhere shifting their focus to energy conservation, is this energy conservation the true catalyst for green engineering?

Green Engineering

The catalyst for research into green engineering is observed almost everywhere. Manufacturing businesses are in economic turmoil, causing even assumingly sure-footed corporations to reexamine their manufacturing practices. New technologies and new legislation are prompting these businesses to introduce earth-friendly concepts at each step in the manufacturing process. Students in major universities are even studying brand new degrees based upon the principles that engineering green will benefit the planet and ensure their job security. Through the examples to be discussed, it will be shown that green engineering is definitely stepping away from the buzzword category, and finding itself to be stronghold on the forefront of the engineering industry.

Green Engineering has been defined by the EPA as "the design, commercialization, and use of processes and products, which are feasible and economical while minimizing 1) generation of pollution at the source and 2) risks to human health and the environment 3) waste in general" (Environmental Protection Agency, 2007).

Minnesota has a strong tie to the EPA, receiving thousands of dollars in grants for the betterment of Minnesotan water, soil, and air (Hedberg, 1996). With such attention, many engineering companies in Minnesota have publicly announced conversion to green methods. These companies are recognizing the necessity to change from traditional methods to more earth-friendly concepts due to economical and legislative pressures.

Advancements in technology are helping build a strong foundation of green engineering

knowledge. This knowledge is allowing manufacturing companies the chance to optimize energy, resources, and lessen the environmental impact their methods have on the planet (Devon, 2008). Many companies are taking that chance and introducing green engineering methodology into applications of all natures. For instance, power-plant emissions are monitored to adhere to EPA requirements. New EPA requirements have been enacted after legislative pressure to ensure lower impact on the environment, thus being a catalyst for power-plants to introduce green engineering methods to meet these new guidelines. Another application utilizing green engineering involves rainforest data collection. Traditional methods meant human interaction with a high impact on the rainforest. Thanks to the introduction of green engineering, scientists are now able to collect their data wirelessly for optimal environmental efficiency (Burger, 2009).

The examples mentioned above are the fruits of novel concepts being emphasized and nurtured. Together, these changes are having a direct impact on the way manufacturing companies do business. As mentioned and referenced above, the changes in how companies do business is bettering the environment, and surprisingly bettering companies' bottom lines.

Companies are implanting green ideas in other ways as well. Why stop at reducing oil consumption when a company can purchase advanced monitoring tools to increase the efficiency of their machines and avoid steep fines that other companies are left footing the bill? This trend is being furthered by a recent study performed by PricewaterhouseCoopers. The study found that "venture capital investment in clean technology applications, such as energy conservation, recycling, water purification, emissions control, and renewable energy tripled in 2006 to more than $1.4 billion USD and grew again in 2007 at nearly 50 percent to more than $2 billion USD" (Wien, 2009). This kind of result is a true example of the cost benefits companies are seeing when implementing green engineering, and green processes in general.

On the Green Track

Project GreenTrac™ is a company vested in these very ideals. Founded in Brisbane, Australia, the company came to fruition as a response to another initiative called Target140. This campaign was started to answer the drinking water shortages that were plaguing the area (Tucker, 2009). During this campaign, workers began to notice the unbelievable amounts of energy wasted on their most important tool - computers. They decided to form a company that would end computer energy inefficiency. Project GreenTrac™ has been growing successfully for the past two years. They monitor the energy use of workplace, and train workforce members to become stewards of energy conservation. If entire companies are filing articles of incorporation under the sole premise of energy conservation, how can businesses of every nature not take notice?

There seems to be a consensus forming that green is better for companies like the Midwestern engineering firm. Implementing green engineering and green ideas answered the San Diego Crime Lab's problems, Project GreenTrac™ is training champions of energy within many organizations throughout the world, and the Energy Star program is recognized by 75 percent of the American public. Research in this area used to be flooded with a myriad of hearsay and opinion. Thanks to the scientific advancement of energy conservation, it can now be shown truthfully that, in some cases, opting for energy-efficient is the better choice. However, some people will claim that energy-efficiency is not the wisest choice for machinery (Templeton, 2008). Could this be true?

Cases that claim non-energy efficient machines prevailed as better, in terms of those utilized in factories and manufacturing companies usually derive from the misunderstanding of efficiency. An old steam boiler may not be as energy-efficient as a brand new, Energy Star

approved electric boiler, but sometimes a worker will tell you it is far more efficient at heating the shop than an electric boiler (Gess, 2009). In Gess' report, the author states that many workers were unable to distinguish a difference between an Energy Star rated boiler and an older model. One such worker was cited with the opinion that the older model heated the shop floor quicker than the Energy Star model. How does a researcher segregate views such as these? Through concrete evidence found in this study, these views will be classified as merely opinions and a true answer to old versus new will be found.

Chapter III: Methodology

The purpose of the study was to make an intricate comparison between the 2004 Forest Liné model and the 2008 Fidia-211 model to determine the true energy cost, performance and machine cost, as well as environmental and intrinsic worker improvement cost to create a whole picture that would recommend one machine over the other for the engineering firm. The conclusion of this study will benefit the engineering firm by supporting either the purchase of the Fidia-211 based upon cost and energy-efficiency, or the previous Forest-Liné machine.

Research Design

This study will use the descriptive-normative-survey approach. The descriptive method involves the description, recording, analysis and interpretation of the prevailing conditions and the present nature of a certain focus. It will include the following processes: analysis, classification, measurement and assessment of the data. Survey refers to the gathering of data regarding current conditions. Normative is used to ascertain the normal or typical condition. The survey will determine the energy-efficiency and cost-efficiency of the Forest-Liné machine versus the Fidia-211 machine and come to a conclusion recommending only one machine. Furthermore, the

research will query the following records: utility statements, power consumption logs, and any other paperwork regarding each individual machine's activity in the span of time indicated.

The procedure will include the general principles of gathering data and use published sources of statistics; energy audits; and content analysis of documentary and verbal material.

Method of Data Collection

The primary source of the data will come from business utility statements from Xcel Energy, Inc. for each of the twelve months in each study year. The business utility statements show data regarding the power consumption of each department within the New Brighton, Minnesota facility. Both the Forest-Liné and the Fidia-211 were located in the east shop floor department of the company. Fortunately for the study, the east shop floor has a separate bus bar for power connection. This newer bus bar was installed for the future expansion of the company. In 2004-2005, it was only connected to the Forest-Liné and a limited number of vacuum pumps and chillers. In 2008-2009, this bus bar supplied power to the Fidia-211 and the exact same vacuum and chillers were attached. This situation aides the study by eliminating other sources of power consumption which would make it very difficult to segregate which machine was drawing what power and costing which amount. Data from these business utility statements will be broken down into three totals: kW usage per day by the east shop floor department, cost per month for the east shop floor department, and final cost for the year. This data will be interpreted to find the cost of each machine to be powered in a normative setting. Normative setting assumes that each machine was being worked the same under that same conditions in the facility. As mentioned in previous chapters, the study will be limited by the neglect of inflation.

The secondary sources of data will come from a variety of places. Logs kept by east shop floor management regarding power consumption will show activity and inactivity for each of the

machines in the study. These logs will also show maintenance and repair costs that will give the study information so a standard cost of repair and maintenance dollar amount can be determined and used as a constant. By determining a constant, there will be no variable of costs to throw off the survey. Another secondary source will be brochures provided by Forest-Liné and Fidia explaining the projected power consumption statistics for each model.

The sources of data previously mentioned will be relatively simple to procure. The Midwestern engineering firm has been working in partnership with the researcher to aide in any way. The firm has provided permissions for the researcher to have access to both the primary source of data, and secondary sources of data. The researcher has signed a contract agreement not to discuss any information found that does not directly relate to the study.

Chapter IV: Results

During the field work pertaining to this study, the researcher was fortunate to have each of the three questions asked relating to the purpose of the study answered to satisfaction. The purpose of the study is to make an intricate comparison between the 2004 Forest Liné model and the 2008 Fidia-211 model to determine the true energy cost, performance and machine cost, as well as environmental and intrinsic worker improvement cost to create a whole picture that can recommend one of the machines as more efficient for the Midwestern engineering firm.

Energy cost is the principal data of the set, utilizing utility records, and logs kept by the shop floor manager to determine the total cost for each machine just to be powered. Performance and machine cost is secondary to energy cost, and relates to the cost of maintenance, as well as any repair cost. This collection of data will give better insight to the true cost of the machine, and help determine efficiency more accurately. The final collection of data in the set is the environmental and intrinsic worker improvement cost. This data is calculated based on the minimal amount of information available on the environmental impact of each machine, including emissions and recycling costs, as well as survey-based opinions of the operator running each machine. Putting the conclusions of the environmental results and the worker's opinion on running each machine, a consensus can be made to give the researcher a picture of satisfaction gained from operating the machine mentally and environmentally. This third set of data just explained is the least substantial set, however, it gives the study a complete image of each machine and will better support the outcome of the first and secondary sets of data.

As explained previously, the data is organized in three sets. Within this section, the results will be presented separately, then put together to compare each machine as a whole and draw a conclusion as to which machine is better for the company. The information will then be presented

to the company.

Energy Cost

According to a plaque fixed to the side-wall of the Fidia-211, the machine uses 3-Phase 460 volt power, with a peak consumption of 100 KvA. This number was verified by internal logs kept by the shop floor manager. This calculation is also verified by the maintenance supervisor. Using a standard converter, 100 KvA converts to 80 kWs. Our study found a standard constant of 80% usage of peak power for 24 hours fit the study best. That would be 64 kWs per hour. According to Xcel Energy utility bills included in the study, the average cost of power was maintained at $.07 per kW/h. Using this amount, the Fidia-211 would cost $107.52 per day to run assuming 80% power consumption. This would translate into $3,225.60 per month on average, and $38,707.20 per year.

The Forest-Liné had a similar plaque affixed to its side-wall. According to the plaque, the machine used 3-Phase 460 volt power, with a peak consumption of 125 KvA. This number was confirmed using internal logs kept by the shop floor manager. The calculation and determined data was also confirmed by maintenance supervisor. Using a standard converter, 125 KvA converts to 100 kWs. Our study used the same constant for the Forest-Liné as with the Fidia-211. With an 80% usage of peak power and a 20% usage of off-peak power in the span of 24 hours, that would equate to 80 kWs per hour. According to Xcel Energy utility bills included in the study from the years 2004-2005, this would come to $134.40 per day to run. That cost would then translate to $4,032.00 per month and $48,384.00 per year.

Performance & Machine Cost

According to the shop floor manager logs, the Forest-Liné machine had three separate

repairs completed during the time-frame of the study. One repair was considered "major" and two were considered "minor". The major repair cost the firm a total of $758.00. The two minor repairs each cost $134.00 and were considered replacement costs due to misuse. This equates to a total cost of $1,026.00.

The Fidia-211 had two separate repairs completed during the time-frame of the study. Both repairs were considered "minor" and were due to fatigue of components within the machine. The first repair involved the replacement of some wiring, costing the Midwestern engineering firm $560.00 in charges. The second repair involved a damaged keypad and cost the company $287.00 in charges. This comes to a total cost of $847.00.

The engineering firm also employed extra workers on an as-needed basis for cleaning the machines. According to the accounting department, the company paid out $408.00 in wages for these as-needed workers during the study time-frame for the Forest-Liné. For the Fidia-211 time-frame, the company paid out $412.50 in wages to as-needed employees.

Shop floor logs also account for cleaning supplies requested by the extra workers. After the supplies are requested, they go through purchasing for approval. Once approved, the supplies are purchased and logged once again in the shop floor log book. The supplies approved and purchased for the Forest-Liné study amounted to $107.65. The amount approved and purchased for the Fidia-211 study came to $78.98.

Given the aforementioned information, the results of these sets of data come staggeringly close. A total of $1,541.65 was spent to repair and/or maintain the Forest-Liné machine during the included study time-frame. A total of $1,338.48 was spent to repair and/or maintain the Fidia-211 during the included study time-frame. That equates to a difference of $203.17.

Environmental & Intrinsic Worker Improvement Cost

During the study, a very interesting piece of information was discovered. According to rules and regulations, the shop floor manager was required to log the coolant intake and output for each of the machines in the study to adhere to protocols regarding tax incentives. The company receives a quarterly tax break when it properly recycles fluids from the machines, as well as when the company passes emissions testing that occurs biannually. This is quite interesting because this information is not common knowledge among the staff and came as a surprise subset of data to the researcher. This is a huge discovery in terms of worth for each machine. The tax incentives that the engineering firm gets paid for each machine could make or break the argument for one or the other.

The following chart shows the data taken from the shop floor log book for each month in the Forest-Liné study period. The months are presented with the approximate amount of coolant used in the machine. Numerically, the coolant amount is displayed in gallons. The cost per gallon of coolant is irrelevant to the study. However, the savings earned from applicable state grants and programs is quite relevant and is presented below for that reason.

Table 1	
February	**226.0**
March	**235.0**
April	**250.0**
May	**252.0**
June	**246.0**
July	**230.0**
August	**224.0**
September	**220.0**
October	**242.0**
November	**240.0**
December	**242.0**
January	**244.0**

The following chart shows the data taken from the shop floor log book for each month in the Fidia-211 study period. The months are presented with the approximate amount of coolant used in the machine. Numerically, the coolant amount is displayed in gallons.

Table 2	
July	**226**
August	**226**
September	**230**
October	**201**
November	**235**
December	**220**
January	**245**
February	**238**
March	**240**
April	**240**
May	**229**
June	**230**

The tax incentive offers companies a 19% grant to cover program cost for recycling within manufacturing companies. Following that allowance, the state will also match 25% of the granted program cost if the company adheres to biannual emissions testing (Boelter, 2009).

According to the shop floor manager, and confirmed by the accounting department, it costs the firm $.29 to recycle each gallon of coolant that flows through the east shop floor machine through approved methods. Using that figure, accounting approved 2,851 gallons of coolant to be purchased, used, and recycled using approved methods to qualify for the tax incentives offered by

the State of Minnesota during the study period regarding the Forest-Liné. That equates to $826.79 spent in recycling coolant by the company. Applying the tax incentive, that equates $157.10 granted by the State of Minnesota, and $206.70 in a follow-up matched grant. Adhering to these regulations saved the Midwestern engineering firm a total of $363.80 during the Forest-Liné study.

The Fidia-211 machine ran 2,760 gallons of coolant during the study period, equating to $800.40 spent by the company to recycle each gallon. Applying the tax incentive, that equates to $152.08 granted by the State of Minnesota and $200.01 in a follow-up matched grant. This means the company saved $352.09 during the Fidia-211 study in state grants and programs.

A survey was given to the operator regarding the performance of each machine, as well as his personal opinion in relation to the satisfaction of working on each machine. The operator is a 37 year-old male journeyman machinist with 17 years experience and 12 years at his job with the engineering firm. The survey results are as follows:

What length of time did you operate each machine?

"The Forest-Liné I ran for its entire time in the east shop floor. That would be about four years. I operated the Fidia since it was installed, and that has been going on for about two years now."

Which machine required more training to operate to the company's satisfaction?

"The Fidia by far. The Forest-Line had all the typical paperwork and manuals, but it felt more traditional and more accessible. The Fidia, while being brand new and futuristic-looking, seems a little more intricate than the old machine."

Do you personally feel more satisfaction working with a machine that boasts to be more environmentally friendly?

"The Fidia is great, don't get me wrong, but on a nuts and bolts comparison, it's the same

machine as the Forest-Liné. The manual can tell you it conserves energy, and has prettier LEDs than the competitor, but on an operational level, it's still chugging along, drinking coolant like no other. The Fidia is just as dirty, loud, and mammoth as any of the machines out there, including the one they replaced it with. The difference is how we work that machine, and how we reduce our own waste."

Can you explain?

"It's all up to the operator. One man I worked with used to overload on materials, or let it chug all the coolant it [the machine] wanted. A good operator will learn the machine, and know what is required at a minimum to get the job done and save time and money. I don't waste fluids, I don't jam-pack the bays, and I make sure the spindle is off and that machine is on standby whenever it is not in use. In my opinion, those machines are great if you've got an experienced operator making the best use of them. Otherwise they are an opportunity for a company to lose a lot of money just by having inexperienced staff working on them. "

In your experience, has inexperienced staff caused the majority of problems with these machines?

"As I'm sure it shows in the logs, the Forest-Liné had a couple repairs back in the day due to some novice machinists making some bigger mistakes. One guy accidentally powered down the machine when it was it was in the middle of an operational cycle. The guy just accidentally pushed the E-Stop (Emergency Stop) button and the entire machine rattled to a stop. Scrapped a major and very important part that needed to be finished by a deadline. Had to bring in mechanics to fix the machine and carefully remove all the damaged materials. Sure wasn't cheap. It cost the company time, money, and despite the fact that the customer still continues to deal with us, I feel our reputation was tarnished due to this incident."

Were repairs done on the Forest-Liné during its service due only to misuse or were there any other

factors?

"That Forest-Liné is a tough machine. The only reason we needed anyone to come in and fix her was because of errors on the behalf of my team. Not once do I recall, and the log books will back me up, the necessity of any repairs due to fatigue or machine failure. I think that is why some prefer her. The Fidia has had a bunch of little repairs and maintenance issues. I think that a new machine like her should be built tougher, but instead, there's just more things to go wrong with it. I always equate it to an iPod or a new cell phone. The more bells and whistles you add, the more problems you could potentially have."

How about the Fidia-211?

"Like I said, that machine has only had issues with fatigue. My problem with it is that it is relatively brand new. A two-year old industrial milling center should still be in pretty substantial working order. For some reason, the wiring started to fatigue after a year. We had to bring in the mechanics to reinstall some of the wiring near the column where the spindle is attached, and then not two months later, the keypad needed to be replaced because some of the numbers weren't responding. Little things like that make someone like me question the resiliency of a machine. That's why I say newer isn't always better. The Forest-Liné may have required more costly repairs, but it was our own fault. The Fidia's problems have been with the machine itself."

Do you believe the Fidia-211 is the better choice for the Midwestern engineering firm?

"To be honest, I was happy with the Forest-Liné, but then again, I sign off on the shop floor logs along with the shop floor manager, and I know the Fidia took in less coolant for a year than the Forest-Liné. I would say that alone is incentive to stick with it. But, if we're looking at usability and the attitude of the shop floor workers, they all seemed to handle the Forest-Liné pretty well."

Do you have any other comments regarding the Forest-Liné machine?

"I think the Forest-Liné machine is a strong argument against the 'newer is better' train of thought. Everyone was pretty surprised when the [energy] audit determined the need for a different milling center. Workers complained to their supervisors about throwing away money and jumping too fast into a new contract with a new machine. Those people liked working with the Forest-Liné. It was a tough machine, and they could throw a lot at it before it hit its limit. But attitude doesn't exactly save money, and it will be interesting to see what the numbers say regarding cost.

Do you have any other comments regarding the Fidia-211 machine?

"The Fidia has been in the east shop floor for almost two years now. My guys have gotten used to the displays, the pads, etc. They seem to enjoy working on it, despite sometimes having to consult the manual when a new-fangled warning pops up. The Fidia has a lot of flash for a machine of that kind. Like I said before, it's almost futuristic. People talk about greenhouse gases and emissions; in fact, it's all they talk about when those inspectors come for testing. It always gets flying colors. If I was one of those people to buy into global warming and all that business, I would say the reward of working on a machine like that is knowing you're producing less of a problem. The machine is supposed to be better for the environment, but I am more interested in how expensive better is. Somebody told me the technology has been out there enough that the Fidia wasn't as expensive as it used to be. If that's the case, then the cost should be pretty equal to the older Forest-Line, and then it would come down to all the smaller costs. Those are the numbers I'd like to see. Because, from an operator's point of view, it's all in how you run your machine. "

A Recap of Results

Energy cost was the primary source of data required in the study. According the calculation of data and the Xcel Energy utility bills, the Fidia-211 cost $38,707.20 per year to power. The Forest-Liné cost $48,384.00 per year to power. That's a difference of $9,676.80 between machines

to operate for the span of 12 months.

In relation to performance and machine cost, a grand total of $1,541.65 was spent to repair and/or maintain the Forest-Liné machine during the included study time-frame. A total of $1,338.48 was spent to repair and/or maintain the Fidia-211 during the included study time-frame. That equates to a difference of $203.17. This data represents the cost to repair and/or maintain each machine, including the cost of extra employees and supplies used.

Regarding environmental and intrinsic worker improvement cost, the Midwestern engineering firm saved a total of $363.80 during the Forest-Liné study by taking advantage of state programs and grants. The company saved $338.27 during the Fidia-211 study in state programs and grants. The survey given to the operator of both the Forest-Line and the Fidia-211 gave insight into the attitudes of him and fellow workers involved with the machines.

In the following chapter, these results will be discussed in full. Discussion and interpretation will prove to be the deciding factor that suggests which machine is the better choice for the engineering firm. The discussion within the following chapter will also show any weaknesses in the data, as well as conflicting ideas. Negatives and positives of the study will be determined. The results will be analyzed and discussed on a task by task basis first, and then will be discussed as a whole. The field problem was to make an intricate comparison between the 2004 Forest Liné model and the 2008 Fidia-211 model to determine the true energy cost, performance and machine cost, as well as environmental and intrinsic worker improvement cost to create a whole picture that can recommend one of the machines as more efficient for the Midwestern engineering firm. These discussions will make sense of the data presented, and answer the field research problem to satisfaction.

Chapter V: Discussions

This study was conducted for the sole benefit of the Midwestern engineering firm. As stated in previous chapters, the purpose of the study was to make an intricate comparison between the 2004 Forest Liné model and the 2008 Fidia-211 model to determine the true energy cost, performance and machine cost, as well as environmental and intrinsic worker improvement cost to create a whole picture that would recommend one machine over the other for the aforementioned engineering firm. The purpose of this chapter is to interpret the results and draw conclusions based upon these results to satisfy the purpose of the study. After all conclusions have been made, a set of recommendations will be explained to benefit any further study done on the matter.

Energy cost is the foremost substantial data set in the study. Energy cost is important because it can show the exact amount the engineering firm is spending to power the machines at a rate of power set for the purpose of the study. In this study, the constant rate of power set was 80% peak power and 20% off-peak power. As mentioned previously, these percentages give the closest-to-accurate power usage to use as a constant. The Fidia-211 milling center costs $107.52 per day to run, which translates to $3,225.60 per month and $38,707.20 per year. The Forest-Liné milling center costs $134.40 per day to run, translating to $4,032.00 per month and $48,384.00 per year. These numbers were verified and accurate according to the internal logs kept by the shop floor manager. According to SedOnline, one of the leading distributors in manufacturing that has lobbied for power consumption monitoring in all aspects of business, "internal initiatives to reduce power consumption will not only better the environment, it will better a company's bottom line" (2009). A statement such as this completely relates to the study by highlighting the importance of the aforementioned result. The Forest-Liné milling center drew more power, and cost the engineering firm more money than the Fidia-211. The total savings the Fidia-211 offers equates to

$9,676.80 per year.

As mentioned previously, when the engineering firm decided to purchase the first machine back in 2004, one of the deciding factors was the price difference compared to the Fidia's comparable machine at the time. Had the engineering firm decided to go with Fidia's comparable machine, they would have spent an extra $11,000. However, given the results from the study, the Forest-Liné devours nearly 90% of that amount by consuming more power and costing the company more money. For the first year, the company would have lost a little over $1,000 by going with Fidia, but in the subsequent years to come, they would have been making money just by using a more energy-efficient machine.

There are other relevant costs to consider before making the decision that the Fidia-211 is superior to the Forest-Liné. One such cost involves performance and the cost of machine maintenance. In the results chapter of this study, the performance and machine cost is considered secondary data to energy cost. However, this collection of data gives depth to the study and better insight to the true cost of the machine. After all, power consumption alone cannot negate a machine's worth. A machine may cost less money in utility bills to power, but if that machine is constantly breaking down or requiring more maintenance, those costs could negate the loss in power consumption cost.

According to the shop floor manager logs, the Forest-Liné machine had three separate repairs completed during the time-frame of the study. One repair was considered "major" and two were considered "minor". The shop floor manager was eager to explain the difference.

According to regulations, a "minor" repair is when a non-certified company technician can repair the problem. This usually means the problem is small, and generally costs under $500.00 to repair. A "major" repair is when certified technicians from the milling center's company is

required to come out and perform the repair and/or maintenance themselves. This usually means the problem is more severe, and generally costs the engineering firm upwards of $500.00-$1,000.00 to repair.

The major repair for the Forest-Liné cost the engineering firm a total of $758.00. The two minor repairs each cost $134.00 and were considered replacement costs due to misuse. This equates to a total cost of $1,026.00.

The Fidia-211 had two separate repairs completed during the time-frame of the study. Both repairs were considered "minor" and were due to fatigue of components within the machine. The first repair involved the replacement of some wiring near the spindle column, costing the engineering firm $560.00 in charges. The second repair involved a damaged keypad and cost the company $287.00 in charges. This comes to a total cost of $847.00

While the Fidia-211 had a smaller repair cost, it seems odd that the only reason for those repairs were due to fatigue. A state-of-the-art brand new milling center should not be experiencing fatigue at such an early juncture. According to the Fidia-211's manual, wiring near the column where the spindle is attached should expect a performance life of 12-24 months (Orenzo, 2008). The fact that repairs had to be performed on that wiring before the manual claims it should is concerning. The damaged keypad is less concerning. Constant pressure on keypad numbers can often cause damage, much like constant pressure on a remote control or wireless phone. According to the Forest-Liné manual, (no data regarding the keypads could be found in the Fidia-211's manual), keypads are expected to have a performance life of anywhere from 8-36 months depending on use (Chabrais, 2004).

Further study into the major repair for the Forest-Liné divulged that the repair was due to an employee accidentally pressing the E-Stop (Emergency Stop) button during an operational

cycle. Material from the part that was being manufactured in the milling center was destroyed and caught inside the machine. As explained previously, this type of repair required certified technicians from Forest-Liné to come to the plant and repair the machine on-site. There were two minor repairs cited in the results also due to misuse. However, the information regarding the misuse is vague.

Despite the Forest-Liné costing more in energy cost, and so far, holding the lead in repair and maintenance costs, it would appear the only reason the repair cost is higher is due to employee negligence. Employee negligence is not the milling center's fault. Fault is found on behalf of the employees of the engineering firm. Unlike the Fidia-211, the Forest-Liné had zero cost associated with fatigue or failure in any way, shape, or form. Therefore, the study will negate the costs associated with repairs performed on the Forest-Liné.

Maintenance in regards to cleaning the machines is a cost associated with the performance and machine cost data set. The accounting department verified paychecks totaling $408.00 in wages for as-needed extra workers to clean the Forest-Liné during the time-span of the study. Accounting verified $412.50 in wages during the Fidia-211 time-frame. That results in about a $4.50 difference. Still technically cheaper for the Forest-Liné, but not exactly ground-shattering data.

Cleaning supplies were also included in the performance and machine cost data set. The purchasing department approved $107.65 in cleaning supplies for the Forest-Liné. Purchasing approved $78.98 in cleaning supplies for the Fidia-211. This equates to a difference of $28.67 between the two machines for supplies used to clean each milling center. These results show the Forest-Liné costing more in cleaning supplies, but not by much.

Given the aforementioned information, the results of these sets of data come quite close.

However, once the negation of the repair cost for the Forest-Liné repairs due to employee negligence, the final numbers are clear. The Forest-Liné officially ran $515.65 in performance and machine costs. The Fidia-211 came to a total of $1,338.48. That would be a difference of $822.83. That means the Fidia-211 is actually more expensive in terms of performance and machine costs than the Forest-Liné. Still, there is too large of a difference in energy costs to consider the Forest-Liné as more cost-efficient. This leaves the study with one last data set to clarify and satisfactorily answer the purpose of the study.

The environmental and intrinsic worker improvement cost study yielded some very interesting information. Prior to the study, no knowledge of the tax incentive programs was available. It was only during several reviews of the shop floor logs that the study was made aware of tax incentives the engineering firm is eligible to receive after noticing a special log for coolant intake and output. That information yielded more knowledge about the engineering firm receiving more tax incentives by passing emissions testing that occurs biannually. This information proved invaluable because it could mean a great additional worth of each machine depending on the amount of incentives each received.

Referencing data submitted in the results section, the engineering firm saved a total of $363.80 during the Forest-Liné study in tax incentives. The Fidia-211 machine saved the firm $338.27. According to this data, the Fidia-211 saved less money for the company. However, referring back to the original data, the Fidia-211 also used 91 less gallons of coolant during the study period. That is 91 extra gallons of coolant the Forest-Liné consumed in one year, and $26.29 extra dollars the engineering firm paid out to recycle that additional coolant. After applying the state program matches that would equate to the company paying an extra $47.00 out-of-pocket in recycling costs. That number is in addition to the extra cost of the coolant in and of itself.

Given this information, the Fidia-211 is still in the lead for cost and savings to the company. The final section of collected data is compiled in interview form. In terms of dollars and cents, the Fidia-211 is ahead of the Forest-Liné by a pretty sizable margin. However, the human element of a company has a great deal to do with how machinery is operated, cared for, and treated. What opinions do the employees have regarding the machines? The study interviewed the primary operator of both machines. Reiterating previous knowledge, the operator is a 37-year-old male journeyman machinist with 17 years experience and 12 years at his job with the engineering firm.

The operator worked the Forest-Liné for about four years according to his survey. He has worked on the Fidia-211 for two years. The time spent on each machine is important, because a longer relationship with one machine might give way to favoritism. However, there is only about a two-year difference between the two machines, so no favoritism is warranted.

The operator seems to consider the Fidia-211 as complicated. He often cites that the Forest-Liné is easier to work with, and less intricate than the other. He also appears not to be swayed by environmental factors such as energy conservation and recycling in terms of each machine. He does state that it is the worker that needs to reduce waste, suggesting he finds more fault on the behalf of employees causing issues with the machines than the machines themselves. His survey response when asked to explain how workers cause waste was quite interesting. Saving time and money is vastly important to all businesses, especially those in manufacturing. The operator reduces his waste by not over-packing the bays and not overusing fluids such as coolant. He also describes putting the machine into standby mode to conserve power whenever it is not in use. The final thought he leaves the question with is that a company loses money just by having inexperienced staff working on the machines. Could that be a way to improve efficiency? Better technical support and training on behalf of the staff could lower performance and maintenance

costs for the machine, thus saving the company financially, and saving employees from making serious mistakes.

One such mistake is referenced multiple times throughout the previous chapters. The incident was caused by employee negligence while using the Forest-Liné. A piece of steel was being milled in the machine on a typical cycle for the project at hand. The worker was talking to another fellow employee when he leaned up against the machine to support his weight. His hand hit the E-Stop button and the machine halted immediately. The part was completely ruined, and the damage inside the machine was extremely difficult to repair. The operator even mentions that he felt the company's reputation was tarnished due to the necessity of extending the contract to redo the part. This type of negligence is unacceptable. It reiterates the idea of better technical support and training benefiting the company and potentially lengthening the life of the machine.

Repairs done on the Fidia-211 are mentioned briefly in the survey. The operator discusses that he feels that the Fidia-211 should be tougher for such new technology. He mentions that the only repairs required to the Fidia-211 resulted from fatigue of the machine. As stated previously, a brand new machine should not be wearing out after a year of use. If the repair cost was higher, perhaps this would be enough of an argument to suggest the Forest-Liné as better for the company. However, the financial aspect is still favoring the Fidia-211.

Unfortunately, the one question asked by the study is answered with hesitation. The operator agrees that the Fidia-211 is probably best for the engineering firm, but then goes on to recommend the Forest-Liné because the shop floor workers enjoyed working with it slightly more. Despite this uncertainty, the operator does come to a conclusion with the final two questions.

The team working with the operator on the Fidia-211 enjoys working on that machine for a variety of reasons. After two years, the team is used to the displays and mechanisms found on the

machine. They are also taking pride in working on a machine that is more environmentally friendly. The Fidia-211 passes emissions testing with flying colors every year. The Fidia-211 also uses less coolant. However, does that mean it beats the Forest-Liné for a concrete recommendation to the company?

Conclusions

In a comparison study such as this, it is difficult to make a recommendation when the results are so close. Throughout the study, one set of data kept showing prevalence over the other subsets. Energy cost turned out to be a huge factor for the study, outshining performance and maintenance costs due to the high dollar amounts. The survey found in the environmental and intrinsic worker improvement cost section was also a vital piece of the study.

The purpose of the study was to make an intricate comparison between the 2004 Forest Liné model and the 2008 Fidia-211 model to determine the true energy cost, performance and machine cost, as well as environmental and intrinsic worker improvement cost to create a whole picture that would recommend one machine over the other for the engineering firm. The study shows conclusively that the Fidia-211, despite being slightly more expensive to repair due to fatigue within the machine, is the best choice for the company. Not only does it save the company in energy costs, it is slowly paying for itself just by reducing waste and controlling power consumption. The Forest-Liné is a good machine, employees will agree, but it drains nearly $10,000 more per year just to power. Considering even the smaller costs associated with the Fidia-211, it still is a better bargain for the company in the long run.

If the study was reexamined or redone, it would be recommended that a more statistical approach be done in place of the survey. Instead of surveying one operator, the researcher could survey the entire team working on each machine in a multiple choice type questionnaire. This

would be helpful to create a concrete statistical analysis instead of an objective approach like the one taken within the current study.

One recommendation aside from the continuation of use of the Fidia-211 would be for the engineering company to implement some sort of additional training on the machine. The biggest issue with the Forest-Liné, aside from the power consumption, was the fact that costly repairs were due to employee negligence or misuse. Additional training and technical support on behalf of the company could benefit the workers and improve how they operate the machinery. Training could end up saving the company even more money by ensuring accidents do not occur. With the frequency of accidents decreased, the cost of repair and maintenance should decrease as well.

One finding in the study that should be applauded is the company's enrollment in government aid programs to help pay for recycling program costs. A company that shows initiative in this aspect of business should be proud. Taking advantage of these types of programs shows that green engineering truly is coming into the forefront of business practices in the manufacturing world.

With all the uncertainty in the economy, Americans are trying to focus their energy on problems they believe they can solve. Global climate change is being paid attention to in every media form. Everywhere one looks, marketing and advertising is telling humankind to go "green". "Green" is hardly a new concept, but new legislation and the growing demand for more earth-friendly products and more-importantly, more earth-friendly manufacturing processes, is driving engineering companies to audit their perspectives on current engineering practices.

This study has helped one such company take an in-depth look at their own engineering practices. Every year, companies are introducing innovated machines that boast even higher energy savings and extremely low power consumption. In the future, the engineering firm

involved in this study may opt to replace their Fidia-211 with a newer, more efficient model. For the time being, however, the company can rest assured knowing their machine is saving them money in many ways, bettering the environment, and giving some employees a sense of pride and enjoyment for working with such a remarkable machine.

Table 3	Forest-Line	Fidia-211
Energy Cost Per Day	$134.40	$107.52
Energy Cost Per Month	$4,032.00	$3,225.60
Energy Cost Per Year	$48,384.00	$38,707.20
Performance & Machine Cost	$1,541.65	$1,338.48
Recycling Costs Before State Programs/Grants	$826.79	$800.40
Yearly Coolant Consumption	2,851.00	2,760.00
Total Yearly Cost For Each Machine	$50,752.44	$40,846.08

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