

Analysis of Energy Recommendations in the U.S. Wood Products Industry

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Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
In
Forest Products

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May 03, 2016
Blacksburg, VA

Keywords: Energy Management, Industrial Assessment Centers, Wood Product Manufacturing, Furniture & Related Product Manufacturing, Lean Management, Lean Manufacturing

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ABSTRACT

As energy prices and demand are projected to increase globally and markets become more competitive nationally and internationally; the wood products industry must find ways to remain relevant. By: 1) analyzing energy-saving recommendations contained in the IAC database; 2) comparing those recommendations by criteria such as cost, savings, and payback period; 3) identifying recommendations that incorporate lean manufacturing principles; and 4) investigating the practices and perceptions of manufacturers at the facility level, this project provides information for identifying the greatest opportunities for energy management among U.S. wood product manufacturers. Results from the analysis of the IAC database show that wood product manufacturers had a low implementation rate of energy recommendations ranked purely by cost, savings, and payback period among wood product manufacturers suggesting they were not focused on implementing energy recommendations specifically based on those criteria. While some recommendations were found to be statistically different in at least one criteria: cost, savings, or payback period between wood and non-wood manufactures as well as primary and secondary wood manufacturers, only two recommendations had practical differences, large payback periods, between primary and secondary wood manufacturers. Twenty-four of 192 energy recommendations were classified as lean-based energy recommendations using the Kirby and Green (2003) methodology, however, there was no clear evidence to suggest the lean-based energy recommendations were superior in terms of cost, savings, or payback period when compared to simple energy recommendations. Interviews with primary and secondary manufacturers revealed

a lack of commitment to energy performance improvement and the reported barriers of implementation among a small sample of wood products manufacturers suggests that the dissemination of energy management knowledge and benefits is a problem.

Acknowledgements

I would like to acknowledge the support of the Forest Service as this research was supported, in part, by the USDA Forest Service, Northern Research Station, under agreement #13-JV-11242301-080.” Also, I would like to recognize the patient and critical feedback from my committee; Dr. Brian Bond, Dr. Henry Quesada-Pineda, and Dr. Janice Wiedenbeck, thank you for your guidance. Lastly, I am especially grateful to my friends and family whom inspired me to continue my education into graduate school and their unwavering support throughout the process.

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CHAPTER 1 – INTRODUCTION

The wood products industry operates in a market with little growth in sales volumes and narrow profit margins (*Ahmad 2014*). These factors require manufactures to rely on economies of scale, well established relationships with suppliers, and low production costs to ensure profitability (*Ahmad 2014*). Methods for lowering production costs include limiting raw material purchases and constricting labor costs, but these only help so much. Timber and lumber prices for softwoods and hardwoods have increased from 2009 to 2014 restraining profit growth for wood products manufacturers (*Ahmad 2014; Neville 2014*). Also, some manufactured wood products are labor intensive or require skilled operators, which limits how much labor costs can be constrained (*Ahmad 2014; Grushecky et al. 2006*).

In the past, energy used for manufacturing was a small portion of the total cost and was accepted as a normal part of business (*Mate 2002; Sciortino et al. 2009; Wengert & Meyer 1992*), however, more attention is being given to energy management as increasing energy prices are impacting profit margins (*Devaru et al. 2013; Espinoza et al. 2011a; Lin et al. 2012; Sciortino et al. 2009*). According to ICF International (2007), control of energy costs are key for obtaining a competitive advantage in the global marketplace and despite the wood products industry being the leader in the use of renewable biomass energy in the U.S., purchased energy remains the third largest production cost, as much as 10 percent of total operating costs, behind raw materials and labor costs (*AF&AP 2014; Ahmad 2014; Gopalakrishnan et al. 2012*).

1.1 Problem Statement

Initial investigations show evidence that the wood products industry (NAICS 321) and the wood-oriented portions of the furniture and related products manufacturing industry (NAICS 337) should be highly motivated to manage energy costs (*Espinoza et al. 2011b; ICF International 2007; Ray et al. 2006*). As energy prices and demand are projected to increase globally and markets become more competitive nationally and internationally; the wood products industry must find ways to remain relevant. Given: 1) the difficulty many wood product manufacturers have in passing on raw material price increases to consumers and 2) the quest for low-cost labor has driven much production overseas, energy management is an excellent method for creating a competitive advantage for remaining U.S. wood product manufacturers (*Ahmad 2014; Espinoza et al. 2011a; Gazo & Quesada 2005*).

Energy management is heavily tied to the implementation of energy-saving practices and the U.S. Department of Energy Industrial Assessment Centers (IAC), a conglomerate of universities performing energy audits of manufacturers nationwide, have compiled a large database of the energy-saving recommendations and their effectiveness among U.S. manufactures. While the information regarding thousands of energy recommendations for many different manufacturing sectors exist, the data is not in a prepared or serviceable format for wood product and wood furniture manufacturers who wish to lower energy costs and become more competitive. By sorting and analyzing the data specific to the wood products industry, this project aims to provide the industry with information that can be used to make the most effective decisions regarding energy-saving practices.

1.2 Objectives

The goal of this project was to analyze the energy recommendations in the IAC database to provide the U.S. wood products industry with information about which practices they should consider to best reduce their energy costs, thus improving their competitiveness.

The specific objectives are:

- 1) Identify and rank energy recommendations given to wood products manufacturers by implementation cost, savings, payback period, and implementation frequency.
- 2) Compare implemented energy recommendations by cost, savings, and payback criteria between wood and non-wood manufacturers and between primary and secondary wood manufacturers.
- 3) Identify energy recommendations from the IAC database, implemented by wood products manufacturers, which incorporate lean manufacturing practices or principles.
- 4) Provide insight on the energy consumption, energy management practices, and perspectives of wood product manufacturers regarding energy management based on a comparative case study.

1.3 Significance

Previous studies have shown that the management of energy consumption and efficiency is an important component of day-to-day wood product manufacturing operations; an importance which is projected to increase as concerns about energy demand and prices continue to grow and manufacturers' ability to affect raw material and labor costs remain difficult. Analyzing energy-saving recommendations for U.S. wood product manufacturers, comparing recommendation's yield between manufacturing groups, and investigating the practices and perceptions of wood product manufacturers at the facility level will provide information for identifying the greatest

opportunities for energy management. Opportunities that reduce operating costs, increase profitability, and reduce vulnerability to energy price fluctuations; therefore, increasing the industry's competitiveness in an international market.

CHAPTER 2 – LITERATURE REVIEW

2.1 Introduction

The objectives listed in section 1.2 bring topics such as energy management, lean manufacturing, the Industrial Assessment Centers (IAC), and the U.S. wood products industry together. In this chapter these seemingly disparate subjects are broken down and organized in a simple fashion beginning with an introduction to energy, energy consumption in the U.S., and the IAC, followed by descriptions of energy management and lean manufacturing, and how these two management philosophies are similar. Next, the wood products industry is introduced and the chapter concludes with how energy consumption has affected the industry and where energy management for the industry stands.

2.2 Energy Basics

Energy is the ability or capacity to do work (*Demirel 2012; U.S. EIA 2015a*). This is a classic scientific definition of energy but it fails to give real insight about energy. It doesn't explain if energy is something to hold in your hand like a pencil; furthermore, how does this relate to energy's availability or cost? To better understand what energy is, it is important to briefly examine the origins of its meaning.

Scientific understanding of energy comes as a result of the First Law of Thermodynamics, which states: a system in which heat is converted to work, the amount of work done is proportional to the sum of heat expended; likewise, if done in reverse, the sum of heat created is proportional to the amount of work expended (*Carnot et al. 1890; Clausius & Hirst 1867; Kumar 2013*). From this law, energy, as it is understood today, was discovered (*Gyftopoulos & Beretta 2005; Kumar 2013*). Therefore, when saying energy is the ability or capacity to do work, what is really being

explained is the mathematical equation that came as a result of this thermodynamics thought experiment. What energy is, is an idealized concept, a conserved property of the universe which can take on different forms. It pervades all physical phenomena and has been used across many disciplines to establish relationships throughout nature, yet, it's not easily comprehensible (*Gyftopoulos & Beretta 2005; Kaufman 2002; Robertson 2007*).

Despite the compressibility of energy's founding in thermodynamics, it is well known that energy can produce mechanical power. Through this perspective, energy has been given a socioeconomic definition. Social theory considers energy a resource essential to provide basic needs and economic activity (*Salvador 2005; Shove & Walker 2014*). Typical energy resources prior to the Industrial Revolution were wood, charcoal, and physical labor exerted by humans or animals (*Smil 1999*). With the advent of steam engines, internal combustion engines, and electric motors energy resources such as coal, petroleum, and natural gas began replacing pre-industry energy resources (*Smil 1999*). For the purpose of this research, the term energy is used in its socioeconomic context; however, energy-saving practices are founded through basic scientific knowledge of energy.

2.3 Energy Consumption in the U.S.

In the U.S., energy resources are categorized into one of two groups: renewable and nonrenewable. Renewable resources are those that are replenished on a human timescale, whereas nonrenewable resources are limited because they are replenished over millions of years (*U.S. EIA 2015a*). Currently, the majority of U.S. energy consumption, approximately 85 to 95 percent, relies on nonrenewable resources such as oil, natural gas, and coal (see **Figure 2.1**) (*Salvador 2005; U.S. EIA 2015a*).

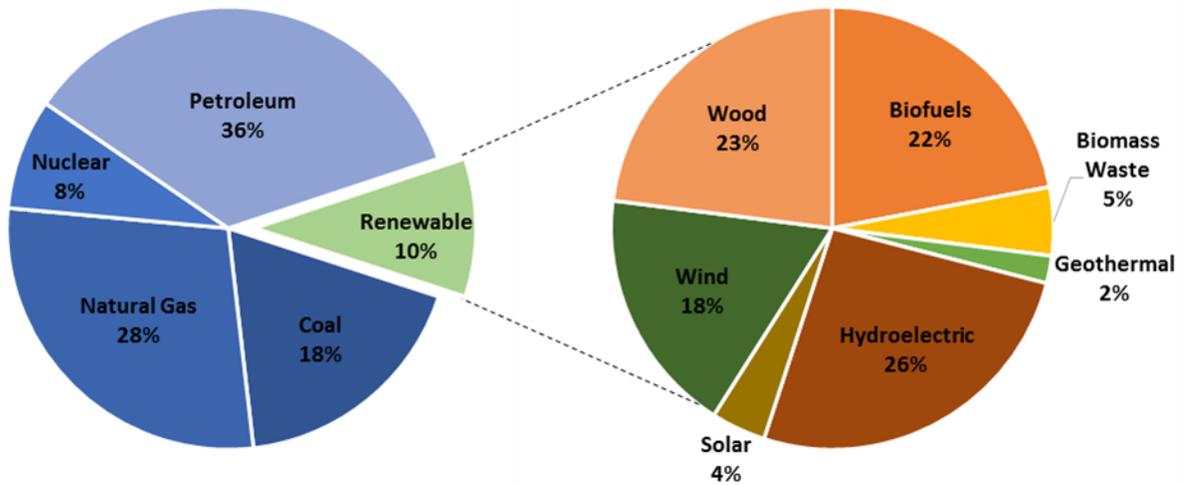


Figure 2.1: U.S. energy consumption by energy source, 2014. Source: (U.S. EIA 2015a).

Energy consumption in the U.S. may be broken down into four major economic categories:

- 1) commercial: consisting of offices, stores, schools, hospitals, and more;
- 2) residential: homes and apartments;
- 3) transportation: any form of vehicle from mopeds to hot-air balloons; and finally
- 4) industrial: manufacturing, agriculture, and construction.

Of those four sectors, industrial energy use was the highest, accounting for approximately one-third of the total energy consumed in 2013 (see **Figure 2.2**) (U.S. EIA 2015b).

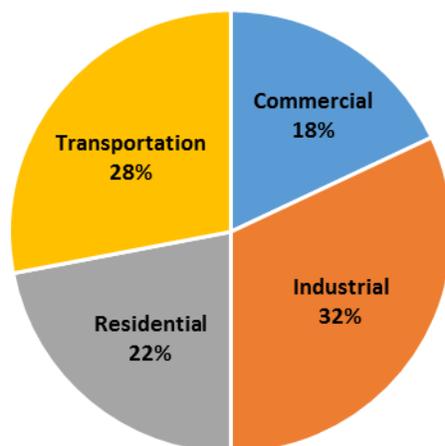
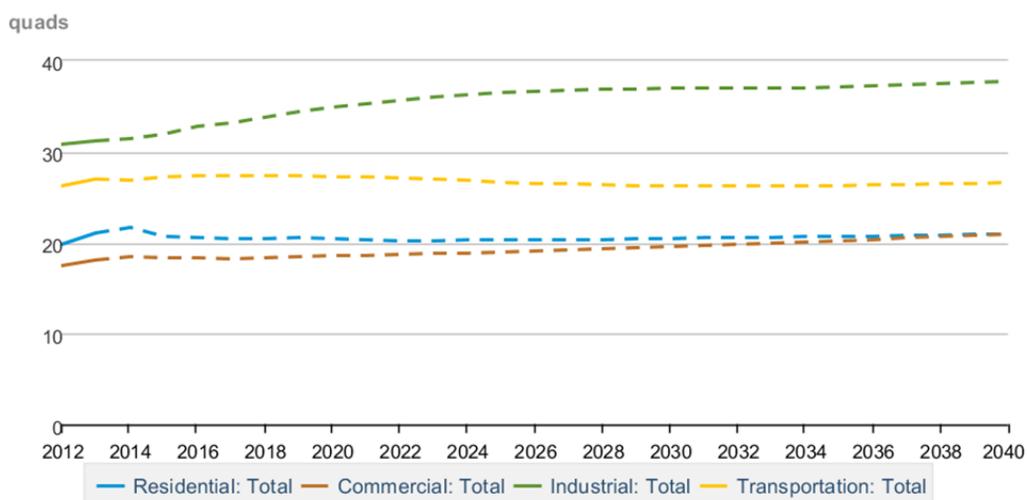


Figure 2.2: U.S. energy consumption by economic sector. Source: (U.S. EIA 2015b).

Energy consumption in the U.S. industry sector has been increasing and is projected to increase over the next three decades; by approximately 15 percent from 2016 to 2040 (see **Figure 2.3**) (Gopalakrishnan et al. 2014; U.S. EIA 2016a).

Energy Use

Case: Reference case | Region: United States



eia Source: U.S. Energy Information Administration

Figure 2.3: Projected energy consumption of U.S. economic sectors. Source: (U.S. EIA 2016a).

Similar to the consumption of energy by the U.S. industrial sector, the prices of energy for the sector are projected to increase over the next few decades as well (see **Figure 2.4**) (*U.S. EIA 2016b*).

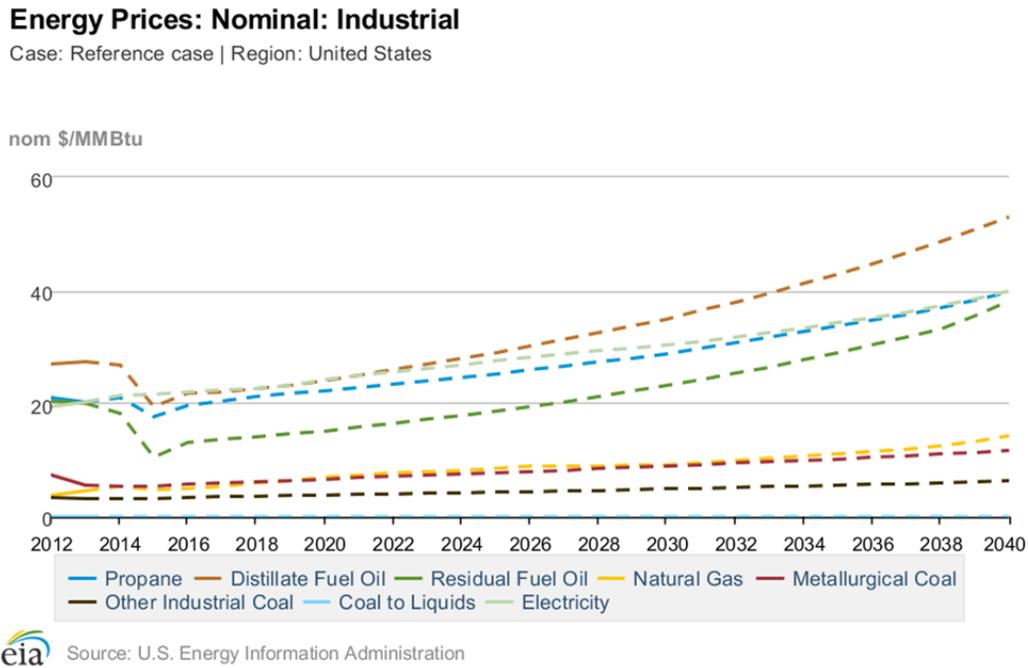


Figure 2.4: Projected energy prices for the U.S. industrial sector. Source: (*U.S. EIA 2016b*).

Electricity and natural gas are the predominant sources of energy consumed in the U.S. manufacturing sector, this also holds true for wood products manufacturers (*Bergman & Bowe 2008; U.S. EIA 2015c*). The price of natural gas for U.S. industry is projected to increase 290 percent from 2016 to 2040 and the price of electricity is projected to increase 81 percent from 2016 to 2040 (*U.S. EIA 2015c*). These rising energy costs and global competition pose continuous challenges for industrial manufacturers but also present opportunity for energy management to play a role in gaining a competitive edge (*ICF International 2007*). For wood products manufacturers, where it is difficult to lower raw material and labor costs, one of the greatest

opportunities to lower manufacturing costs is through reducing energy costs (Ahmad 2014; Espinoza et al. 2011a). Lowering energy costs requires some type of analysis of current energy use and implementations of improvements.

2.4 The Industrial Assessment Centers

The Industrial Assessment Centers (IAC), administered and funded by the U.S. Department of Energy (DOE), are university-based, faculty and student engineer groups that conduct no-cost assessments of small to medium sized U.S. manufacturers across the nation. The scope of the assessments include evaluations of energy consumption, production procedures, and waste production. Currently there are 24 universities that comprise the IAC (see **Figure 2.5**) (U.S. DOE 2016a).

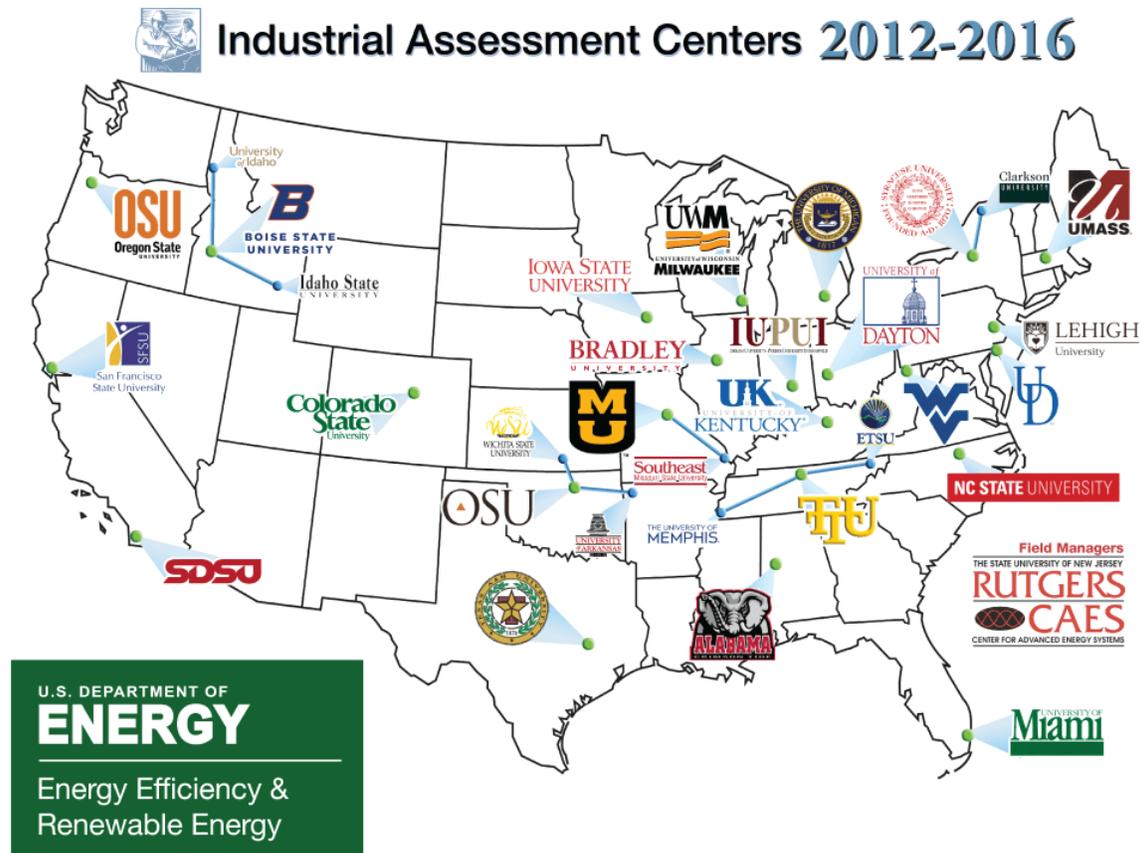


Figure 2.5: Universities currently participating in the IAC program. Source: (U.S. DOE 2016a).

Manufacturers meeting the criteria listed below are eligible for receiving an IAC assessment (*U.S. DOE 2016a*):

- Classify within Standard Industrial Code (SIC) division D, 20-39
- Located less than 150 miles of a participating university
- Gross annual sales below \$100 million
- Fewer than 500 employees at the plant site
- Annual energy bills more than \$100,000 and less than \$2.5 million
- No professional in-house staff to perform the assessment

If the prospective manufacturer is eligible and agrees to participate in an assessment they are sent a pre-assessment form inquiring about the industry they participate in, the area and layout of their facility, their production levels and operating hours, a one year history of their utility bills, and a list of major equipment. Next, all key personnel such as facility managers and maintenance personnel are asked to ensure they will be involved in the process (*U.S. DOE 2016a*).

Back at the participating university, a pre-assessment analysis of the manufacturer is conducted. Their utility bills are charted, graphed and analyzed for trends and errors and a unit of energy is established. Key energy systems are identified while technical and design documents are reviewed and an assessment day strategy is developed (*U.S. DOE 2016a*).

On the day of the assessment the participating university's IAC team gives an introduction to the IAC program then discusses the manufacturing processes and operations such as material flow, defects, bottle necks, inventory levels, and waste generation with the manufacturer. After presenting their pre-assessment analysis the IAC team is given a plant tour in the direction of the

material flow, which is followed by a debriefing and lunch. After lunch the IAC team reviews and refines the list of opportunities to be investigated then conducts diagnostic tests and gathers data on those opportunity areas. The IAC team wraps up the facility assessment with an exit interview used to discuss preliminary findings with the facility management (*U.S. DOE 2016a*).

The IAC team then conducts engineering and financial analysis of their data and develop a report containing a summary of recommendations, descriptions of the facility, process, resource charts and tables, major energy consuming equipment, best practices and details of the energy-saving recommendations. The IAC report is sent to the manufacturer and within six to nine months the IAC team contacts the manufacturer for a follow-up report inquiring about the implementation status and results of the recommendations (*U.S. DOE 2016a*).

The IAC gives, on average, 7.6 recommendations, identifying over \$130,000 in annual savings opportunities, per assessment (*U.S. DOE 2016a; 2016b*). The average number of implemented recommendations per assessment is 3.5, returning over \$40,000 of annual savings (*U.S. DOE 2016a*).

2.5 Common Energy Saving Opportunities

An index of recommendations given by the IAC has been compiled into a manual called The ARC by the Center for Advanced Energy Systems (CAES) at Rutgers University (*Muller & Kasten 2007*). Currently, the recommendation index contains seventeen pages of energy saving recommendations divided into nine main focus areas. The nine focus areas are presented below, each given a general overview along with some common opportunities for energy savings compiled from Gopalakrishnan et al. (2014); Muller et al. (2001); Muller & Kasten (2007); Muller & Papadaratsakis (2003); Worrell et al. (2010); and Wu & Abad (2014).

2.5.1 Combustion Systems

The recommendations given under combustion systems in the IAC index refer to the equipment such as furnaces, ovens, and boilers in which the combustion of fuel is turned into useful heat energy. Common energy savings opportunities come from properly sized equipment operated close to capacity, the monitoring of flue or stack gas, used to optimize the air-to-fuel ratio, maintaining high flame temperature, recovering waste heat, and proper maintenance of the equipment including cleaning, properly insulating, and reducing infiltration.

2.5.2 Thermal Systems

Thermal systems recommendations are aimed at the secondary heat systems that are very closely associated with the combustion systems. The best example of a thermal system, and the one with the largest number of recommendations, is steam. Common energy saving opportunities for steam are largely based on maintenance such as proper insulation, detecting and repairing leaks, and ensuring steam traps are functioning properly.

2.5.3 Electrical Power

Electrical power recommendations affect the overall cost and to some extent the consumption of electricity for a manufacturing facility. Common energy savings come from adjusting power factor, rescheduling operations to reduce peak demand electrical consumption and in some cases installing a combined heat and power (CHP) system to produce on-site energy.

2.5.4 Motor Systems

Motors represent the largest industrial electricity consumer in most facilities, they account for approximately 75 percent of electrical use. The two main opportunities for energy savings

through motors are a result of their selection and operation. When selecting motors, it is important they are properly sized and if possible are a high-efficiency model. Regarding their operation, minimalizing idle time, installing adjustable speed drives, and proper maintenance work to reduce the electricity consumed and in some cases prolong the life of the motor.

Air compressors are listed separately under motor systems in the IAC index and merit their own discussion. Compressed air is a form of stored energy, typically converted from electrical energy by a motor, and is among the most expensive sources of energy used in manufacturing. Approximately 10 percent of the electrical energy consumed by the compressor motor is used to perform work while the other 90 percent is lost as heat. Compressed air should be avoided where possible and used as minimally as possible in necessary applications. In cases where compressed air is necessary, opportunities for energy savings come from using the lowest possible pressure required, reducing the inlet air temperature, detecting and repairing leaks, and recovering waste heat.

2.5.5 Industrial Design

The industrial design section is fairly small when comparing it to the length of other focus areas in the IAC index. The recommendations listed here are aimed at redesigning thermal, mechanical, and miscellaneous processes and/or products with the goal of reducing energy consumption. It is worth noting that the literature used for this project did not discuss redesigning processes or products to save energy.

2.5.6 Operations

The operations focus area acts as the catch-all of any recommendations that had not been mentioned in other sections in the IAC index. Opportunities for energy savings given in this section

are varied but focus on general maintenance and control of energy consuming equipment in a manufacturing facility.

2.5.7 Building & Grounds

Building and grounds include facility lighting, space conditioning, and ventilation. The opportunities for energy-savings in lighting systems come from the removal of unneeded lamps and/or the relocation of lamps, reducing lighting usage by turning off lights when not needed, installation of automatic light controls, and replacing obsolete lamps and ballasts with higher-efficiency models.

Heating, Ventilation, and Air Conditioning (HVAC) opportunities for energy savings come from reduced heating and increased air-conditioning temperatures, maintenance of equipment and ducting, and ensuring the HVAC system is working properly. Consideration should be given to the installation of setback controls, adjustable speed drives, and/or an energy monitoring and control system as they may also contribute to energy savings.

2.5.8 Ancillary Costs

The few recommendations listed under ancillary costs are either administrative or distributive in nature. For example, administrations may find energy cost reductions by checking the accuracy of utility meters or applying for tax-exemptions for purchased energy. Shipping and distribution centers may conserve fuel by consolidating deliveries and increase fuel efficiency with proper maintenance of vehicles.

2.5.9 Alternative Energy Usage

Alternative energy usage is the last, and smallest, section of recommendations in the IAC index focused primarily on implementing solar and wind power.

When beginning an energy management program, the best places to focus initial efforts are areas that consume the largest amounts of energy and work from there. The aforementioned IAC focus areas will apply to a large majority of manufacturers, typically consume the greatest amount of energy, and are commonly found in the literature.

2.6 Lean-Energy Management

It is believed that some energy management practices may not only result in a reduction of energy, but also result in increased productivity. These practices could be interpreted as “Lean-Energy Practices” and are of great interest to many due to their dual benefits. Before discussing the literature about lean-energy this section will describe basic concepts of lean manufacturing and energy management.

2.6.1 What is Lean Manufacturing?

Lean manufacturing was the term chosen to describe Toyota’s automobile manufacturing techniques in the international bestseller “The Machine that Changed the World”; the results of a five-year study conducted by the International Motor Vehicle Program (IMVP) at the Massachusetts Institute of Technology (MIT) (*Womack et al. 1990*). John Krafcik, coined the term “lean” after observing Toyota produce similar results as the current mass-production techniques while using essentially half the resources (*Womack et al. 1990*).

The traditional mass-production method of producing profit is to set a price for goods based on the cost of production, plus whatever profit margin is deemed acceptable. Due to the fixed nature of costs, the primary way to increase profit is through increasing price; which the market may or may not bear (*Monden 2012; Womack & Jones 2003*). Under the lean method of producing profit, price cannot be adjusted. Thus, to increase profit, a company is left to reduce cost and/or improve productivity (*Monden 2012*). To achieve cost reduction and productivity improvement various wastes must be eliminated; this is the principal goal of lean manufacturing (*Quesada and Buehlmann 2013*).

2.6.2 What is Energy Management?

Literature has provided an abundance of definitions for energy management; each written specifically for a given context. For example, energy management is:

“...a combination of design and management function, which embraces the disciplines of engineering, mathematics, accounting, operations research, software engineering and environmental management.” (*Darkwa 2001*)

“[a] set of interrelated or interacting elements to establish an energy policy and energy objectives, and processes and procedures to achieve those objectives” (*ISO/PC 242 2011*)

“The efficient and effective use of energy to maximize profits (minimize costs) and enhance competitive positions” (*Caphart et al. 2012*)

Energy management, as established in this work, will be considered as: the observation, measurement, and control of energy consumption and/or efficiency in manufacturing processes with the goal of managing or reducing costs.

2.6.3 Common Elements

Many key aspects of energy management and lean manufacturing are similar or compatible (*Gopalakrishnan et al. 2012; Kissock & Seryak 2004; Milward et al. 2013; Quesada and Bond 2013; Ross & Associates 2011; Sciortino et al. 2009*). Described below are five common elements of both energy management and lean manufacturing compiled from Čiarnienė & Vienažindienė (2012); ISO/PC 242 (2011); Liker (2004); Milward et al. (2013); Ross & Associates (2011); Sciortino et al. (2009); U.S. EPA (2013, 2014); and Womack et al. (1990).

Commitment

Commitment is the first common element of a successful energy or lean management program. Senior management must clearly communicate the need for change and commit to supporting the transformation effort to everyone in the organization. Explicitly creating a policy that reflects objectives, establishes responsibility and authority, and ensures necessary resources and funding formalizes an organizations' commitment for employees, the community, and shareholders. Appointing informed and active leadership across different divisions of the organization reinforces this commitment and supports the involvement of the employees in all aspects of the project.

Assessment

The second common element of successful energy or lean programs is an assessment of the current state of operations. For energy management this means collecting and evaluating current and past energy consumption for all major operations creating a baseline for measuring and identifying opportunities to improve energy performance. In lean management this means defining value through a customer's perspective, then creating a value stream map (VSM) detailing each step of production from raw material acquisition to finished product delivery. The

combination of defining value and mapping production processes allows the organization to classify operations that: 1) add value; 2) do not add value but are unavoidable; or 3) do not add value and are avoidable.

Planning

The third common element of success for energy or lean programs is a detailed plan of action. Defining methodologies for change, identifying target areas, determining necessary resources and roles all propagate transformation and provide systematic steps for achieving the organizations' goals.

Cooperation

The fourth common element of success for energy or lean programs is cooperation. The level of support and cooperation of employees directly impacts the effectiveness and progression of these management programs. Both management styles require behavioral and cultural adaptation among employees. Practices, tools, and techniques address the behavioral aspect, however, communication, training, motivation, and reinforcement are the guiding principles for the cultural change.

Continuous Improvement

The fifth common element of successful energy or lean programs is continuous improvement. Sustained improvements in either management program is a result of constantly striving for zero waste or 100 percent efficiency. Proper measurements and monitoring of performance will reveal successes and opportunities for additional improvements. Practices and policy must be formally reviewed on a periodic basis to ensure adequacy and updated accordingly.

2.6.4 Incorporating Energy Management and Lean Manufacturing

In addition to the common elements presented above, pioneering research has been conducted during the past decade regarding the incorporation of lean and energy. It has been revealed that due to lean's focus on identifying hidden wastes and eliminating non-value added activities, energy savings are often an ancillary gain of lean practices (see **Table 2.1**) (Milward et al. 2013; Ross & Associates 2011; Sciortino et al. 2009).

Table 2.1: Energy consumption hidden in lean wastes. Source: (Ross & Associates 2011).

Waste Type	Energy Use
Overproduction	<ul style="list-style-type: none"> • More energy consumed in operating equipment to make unnecessary products
Inventory	<ul style="list-style-type: none"> • More energy used to heat, cool, and light inventory storage and warehousing space
Transportation and Movement	<ul style="list-style-type: none"> • More energy used for transport • More space required for work-in-progress (WIP), movement, increased lighting, heating and cooling demand, and energy consumption
Defects	<ul style="list-style-type: none"> • Energy consumed in making defective products • More space required for rework and repair, increased energy use for reprocessing, as well as, heating, cooling, and lighting
Over-processing	<ul style="list-style-type: none"> • More energy consumed in operating equipment related to unnecessary processing • Use of right-sized equipment often results in significant reductions in energy use per unit of production
Waiting	<ul style="list-style-type: none"> • Wasted energy from heating, cooling, and lighting during production downtime

Despite the evidence of links between the elimination of manufacturing waste and the reduction of energy consumption, energy performance is not currently considered a lean goal (Milward et al. 2013; Ross & Associates 2011; Sciortino et al. 2009; Womack et al. 1990; Womack & Jones 2003). This has lead researchers to believe that significant opportunities for improving energy performance and reducing manufacturing costs are overlooked by lean without specific

consideration of energy waste (*Milward et al. 2013; Ray et. al 2006; Ross & Associates 2011; Sciortino et al. 2009*).

From the other end of the spectrum, other studies have been finding strengths in combined energy management and lean manufacturing. Ray et al. (2006) concluded that improvements directed at energy reduction may be the most significant contribution to lean production while developing an index to quantify the “leanness” of manufacturers. Some years later, Lyon et al. (2014) measured the impact of lean processes on the energy consumption of a cabinet manufacturer by collecting real-time electrical consumption data while conducting lean practices such as value stream mapping and kaizen events. The results showed a significant difference in electrical consumption before and after the implementation for each day of the week. This work corroborates the work of Ross & Associates (2011) who report that companies can enhance their lean performance by incorporating energy efficiency opportunities in their lean activities.

The work of Quesada & Bond (2013) and Quesada-Pineda et al. (2015) was a catalyst for the investigation of lean-based IAC energy-saving recommendations conducted in this research. Quesada & Bond (2013) concluded that the top lean-based energy recommendations can lead to greater savings and relative shorter payback periods than the top simple energy recommendations. While both simple energy recommendations and lean-based energy recommendations decrease energy consumption, lean-based energy recommendations had the added strength of improving productivity at the same time.

As more literature is added to the topic of energy management and lean manufacturing, one conclusion has encompassed it all; not all the elements of lean manufacturing and energy management are known and more research to discover and explore those elements is the next

challenge in maintaining progress (*Gopolakrishanan et al. 2012; Lyon et al. 2014; Milward et al. 2013; Quesada & Bond 2013; Ray et al. 2006; Womack 2007*).

2.7 The Wood Products Industry

Industries engaged in wood products manufacturing may be classified under one of two subsectors in the North American Industry Classification System (NAICS), the standard classification system used by Federal agencies (*U.S. Census Bureau 2015*), wood products manufacturing or furniture and related product manufacturing. Wood products manufacturing (NAICS 321) encompass industries primarily involved in manufacturing wood products such as dimension lumber, veneers and plywood, engineered wood products, flooring, trusses, pallets, and other miscellaneous wood products from both hardwoods and softwoods (*U.S. Census Bureau 2012*). Furniture and related product manufacturing (NAICS 337) encompasses any industry primarily involved in manufacturing furniture regardless of the type of materials being used, such as fixtures, mattresses, cabinetry, and window blinds (*U.S. Census Bureau 2012*).

Within the wood products industry a semi-formal classification exists dividing manufacturers between primary and secondary manufacturers. Primary manufacturers are those that process raw timber (logs). Their core operations are chipping/sawing, planing, optionally drying, and shaping products from logs to produce chips, lumber, veneer, engineered wood products such as plywood or OSB, and construction members to list a few (*Hughes & Volsky 2000; Smith et al. 2009*). Secondary manufacturers are those that remanufacture or further process the products of primary manufacturers contributing added value. Some examples of secondary wood products are moldings, cabinetry, crafts, furniture and related articles or even surfaced or dried

lumber from a producer that solely purchases material from a primary manufacturer (*Cesa 1993; Hughes & Volsky 2000; Smith et al. 2009*).

It must be stated that while pulp and paper products are considered forest products, that industry is not included in wood products manufacturing. Pulp and paper represent their own industrial classification which includes pulp mills, paper mills, paperboard mills, stationery production, paperboard container production, and sanitary paper production to list a few (*Leefers 2015; U.S. Census Bureau 2012; U.S. DOL 1987*).

2.7.1 The Wood Products Industry Market

Since the early 1990's, U.S. wood products industries have been subjected to increasing foreign competition (*Buehlmann et al. 2003*). For example, during the early-to-mid 2000's, it was estimated that 35 to 40 percent of all wooden residential furniture sold in the U.S. was imported (*Buehlmann et al. 2003; Bumgardner et al. 2004; Gazo & Quesada 2005*). U.S. demand for imported household furniture has been steadily growing and was estimated to reach 56 percent in 2015 (*Ruiz 2015*). Regarding the U.S. wood products industry as a whole; the value of imports strongly outweighs the value of exports (*Ahmad 2014; Daniels 2008; Neville 2014*).

The majority of goods produced by the wood product industry are used in residential housing construction and residential housing; this results in a positive correlation between the value of residential construction and industry performance (*Ahmad 2014; Neville 2014*). Towards the end of 2007 through 2009, the U.S. was met with a collapse of its housing market and subsequently entered a deep economic recession. During the course of the recession, single-family housing starts decreased by 74 percent and multi-family housing starts decreased by 69 percent, leaving wood product industries reeling (*Howard & Westby 2013*).

During the economic downturn, the combination of emerging competition and economic turmoil, among others, resulted in job losses, plant closures, mergers, bankruptcy, and declining profit margins in wood products industries (*Neville 2014; Quesada & Gazo 2006*). Companies that weathered the storm are slowly recovering, as consumer spending and the housing market spur demand for wood products (*Howard & Westby 2013; Neville 2014*). However, the industry may be missing opportunities to reduce costs through energy management practices, thereby increasing its competitiveness (*Espinoza et al. 2011b; Lin et al. 2012; Lyon et al. 2014*).

2.9 The Wood Products Industry and Energy

2.9.1 Primary Manufacturing

Electrical and thermal energy are the main types of energy consumed by primary wood products manufacturers (in this example, sawmills); however, the total amount of energy consumption will vary significantly depending on the species and products sawn, the age of equipment, the region of operations, and whether the manufacturer chooses to perform all the typical sawmill operations as seen in **Figure 2.6** (*Bergman & Bowe 2008*).

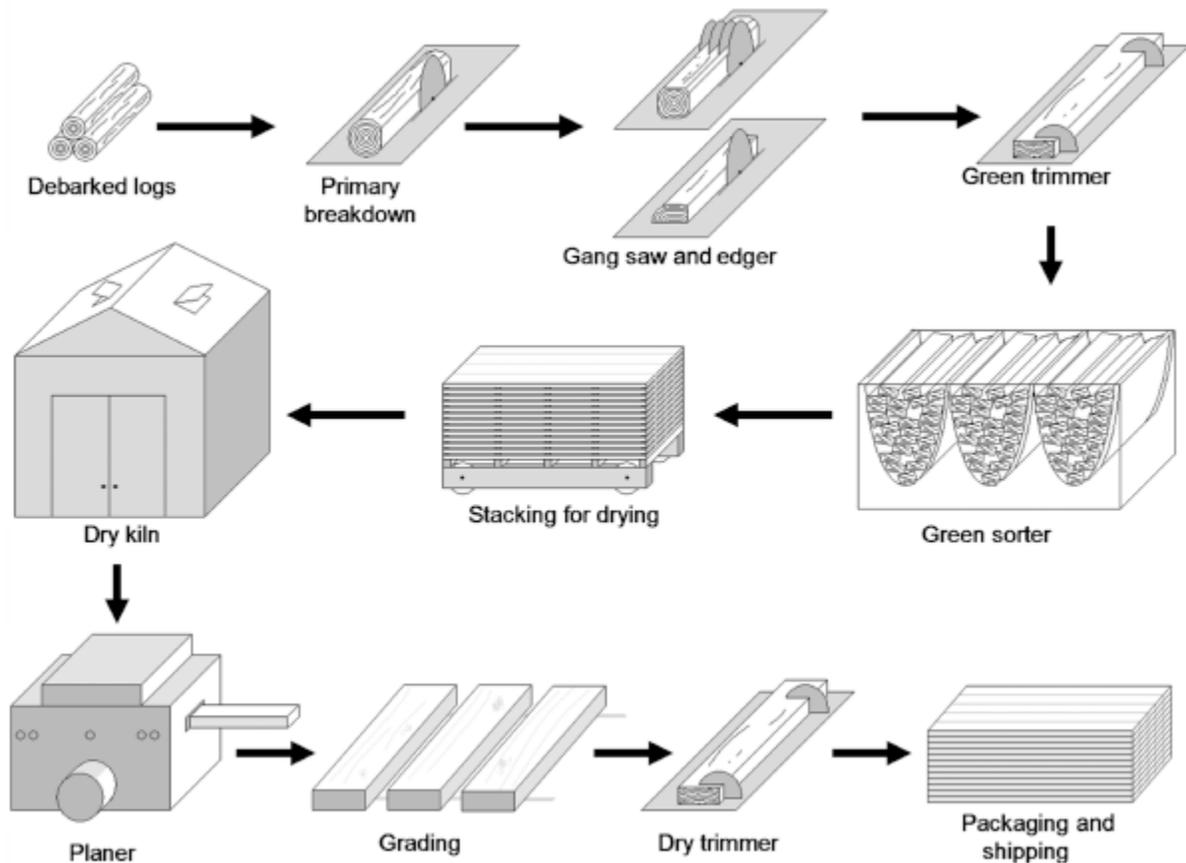


Figure 2.6: Typical sawmill operations flow chart. Source: (Shmulsky & Jones 2011).

Drying operations contribute between 70 and 80 percent of the total energy consumption (both electrical and thermal) while motors used in sawing operations consume the greatest amount of electrical energy in wood products manufacturing (Bergman & Bowe 2008). This is important as not all hardwood sawmills dry lumber, but the majority of softwood sawmills do.

Most softwood lumber is used as building construction material and sometimes for decorative or finishing purposes such as paneling, trim, decking, etc. The largest portion of softwood construction lumber is produced as dimension lumber, which must be dried and surfaced as part of its grading requirements (Shmulsky & Jones 2011). Many softwood sawmill operations include all the steps present in Figure 2.7. In the case of hardwood lumber, the higher grades are

used to produce furniture, cabinetry, flooring, and millwork while lower grades are used in pallets, containers, and railroad ties. Due to the nature of uses of hardwoods, their grading criteria are based on the percentage of face-area that is usable as clear wood, or in other words blemish free. Therefore, hardwood sawmills are not required to dry their products and manufactures may choose to sell only rough (unplaned) green (undried) lumber (*Shmulsky & Jones 2011*).

In general, hardwood production typically consumes more electrical and thermal energy than softwood production (*Bergman & Bowe 2008; Devaru et al. 2013; Espinoza et al. 2011a*). This is likely due to multiple reasons, for example, hardwoods are more likely to be converted to high-grade lumber and subsequently require longer drying times to prevent lumber degrade. Also, hardwoods typically contain higher amounts of water due to their high density which requires larger amounts of energy to remove. Hardwoods are typically dried to a moisture content of 6-8 percent where as softwoods are dried to 15-19 percent; as the target moisture content decreases, the length of drying time and amount of energy consumed increase. Hardwoods are typically sawn to thinner dimensions incurring more sawing time and electricity consumption. Furthermore, as densities of species increase, so too will the electrical energy consumed to process those species (*Bergman & Bowe 2008; Devaru et al. 2013*).

2.9.2 Secondary Manufacturing

The majority of literature found regarding energy and the U.S. wood products industry focuses on primary manufacturers or lumber drying, which can be performed by either primary or secondary manufacturers, thus limiting the discussion on secondary manufacturing.

Between 1994 and 2003 the Industrial Assessment Center (IAC) at Mississippi State University (MSU) conducted over 30 assessments of wood-furniture manufacturers. The results of

those assessments revealed that electric and natural gas were the primary forms of energy purchased by secondary manufacturers, the break-down of where the energy was consumed may be found in **Figures 2.7** and **2.8** (*Emplaincourt et al. 2003*). Natural gas consumed in operations such as paint drying and packaging made up the 48 percent of usage in process equipment (*Emplaincourt et al. 2003*).

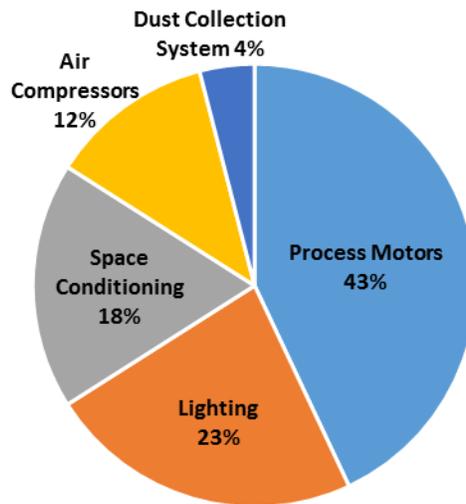


Figure 2.7: Average electrical end-point usage of secondary manufacturers. Source: (Emplaincourt et al. 2003).

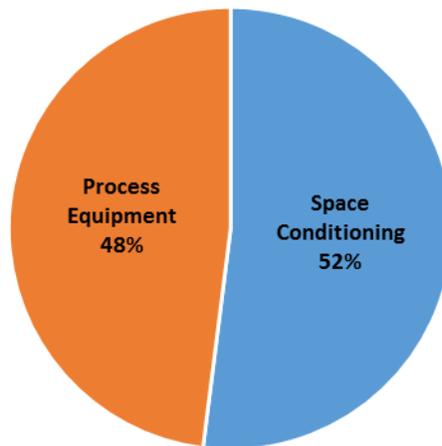


Figure 2.8: Average natural gas end-point usage of secondary manufacturers. Source: (Emplaincourt et al. 2003).

Work conducted by Espinoza et al. (2011a) on energy and the U.S. hardwood industry surveyed both primary and secondary manufacturers, and compared responses between the two. Of the 188 respondents, 41 percent were primary manufacturers, the rest were secondary manufacturers. They found that just over a third of the respondents dried lumber and companies with drying operations were almost equally divided between primary and secondary manufacturers. The difference found between primary and secondary manufacturers was in the average share of energy expenses on total costs. Energy expenses for primary manufacturers was 9.7 percent, while expenses for secondary manufacturers was 7.1 percent. This difference of expense was attributed to the more energy-intensive nature of primary manufacturing (Espinoza et al. 2011a).

2.9.3 Common Energy Saving Opportunities for the Wood Products Industry

According to Wengert and Meyer (1992), the seven major energy consumption areas for sawmills are heating, lights, electric motors, compressors, saws, boilers, and dry kilns. The

common recommendations given to the 30 plus wood-furniture manufactures as reported by Emplaincourt et al. (2003) were directed at lighting, HVAC, dust collection systems, air compressors, power factor, and recovering waste heat. While the recommendations proposed to secondary manufacturers echoed the recommendations provided in section 2.5; saws and dry kilns were not addressed specifically.

As mentioned previously, not every wood product manufacturer performs drying operations, but those that do should assess their kiln(s) first as they are typically the least energy efficient and most energy intensive operating process, using six to nine times more energy than an entire sawmilling operation (*Elustondo & Oliveira 2006; Kudra 2004; Wengert & Meyer 1992*). Opportunities for energy savings in conventional dry-kilns are tied to efficient operation and proper maintenance. Energy saving opportunities for sawing are heavily tied to the motor used in the operation. Recommendations, such as, use thinner kerf, properly lubricate regularly, and keep blades and teeth as sharp as possible will only provide minimal savings unless they result in the ability to utilize a smaller motor (*Lin et al. 2012; Wengert & Meyer 1992*).

2.9.4 Energy's Impact on the Wood Products Industry

The impact of energy costs on the industry can be demonstrated using the results of a study determining the impact of increasing energy prices on the profitability of hardwood manufacturers in the eastern U.S. Approximately half of the respondents reported rising energy prices had negatively impacted their profits between 5 and 15 percent (*Espinoza et al. 2011a*). Most companies indicated they were focused on improving energy efficiency and productivity; however, only 8.6 percent of the companies had established energy use baselines and only 4.9 percent established performance indicators (*Espinoza et al. 2011b*). The authors concluded that companies

were most often implementing energy related projects as one-dimensional efforts rather than part of a long-term continuous improvement initiative (*Espinoza et al. 2011b*).

The only insight to reasons why wood product manufacturers chose not to implement energy saving practices come from Emplaincourt et al. (2003) who cited reasons for failure to implement energy-saving recommendations were: 1) lack of time, primary responsibilities of day-to-day operations left no time to plan and implement recommendations; and 2) lack of funds, budget constraints did not allow for money to be spent, regardless of payback period.

Espinoza et al. (2011b), *Lin et al. (2012)*, *Lyon et al. (2014)*, and *Quesada & Bond (2013)* have shown that opportunities for energy conservation and cost savings through energy management exist for wood product manufacturers, and while the current state of energy may not seem alarming, energy prices are expected to increase as global energy demand increases which will affect future profit margins (*EEF 2014; Sciortino et al. 2009; Seow & Rahimifard 2011; U.S. EPA 2013, 2014*). Given there is limited opportunity for wood products manufacturers to lower raw material or labor costs, serious energy management habits should be formed now as energy consumption is, to a large extent, directly controllable by wood products manufacturers (*Ahmad 2014; Espinoza et al. 2011a; Neville 2014*).

CHAPTER 3 – METHODOLOGY

3.1 Introduction

In this chapter the procedures for fulfilling the four objectives listed in section 1.2 are presented. Because objectives 1, 2, and 3 require to some extent the same data source, the IAC database, methods that were applied to the IAC database are presented first, followed by objective specific methods.

3.2 The IAC Database

Data used for objectives 1, 2, and 3 were obtained from the Industrial Assessment Centers (IAC) database; available online and via download at <https://iac.university/#database>. The version of the database used in this research was downloaded on 02/22/2015 and included a collection of over 16,000 manufacturer assessments with more than 100,000 recommendations dating back to 1981. It is important to mention that the database is a living document, therefore, any alternate version may not be exactly similar. All henceforth reference to the IAC Database is a reference to the 02/22/2015 version.

The IAC database was downloaded as an Excel file containing 6 worksheets, the names and contents are shown in **Table 3.1**.

Table 3.1: Original IAC database layout.

Worksheet	Entries	ID Range
ASSESS	16,770	
RECC1	30,000	(WV0503 – TN0428)
RECC2	30,000	(TN0428 – NC0518)
RECC3	30,000	(NC0518 – KG0022)
RECC4	30,000	(KG0022 – AR0195)
RECC5	6,706	(AR0194 – AM0001)

The ASSESS worksheet contained information specific to the assessed manufacturer, such as: the Standard Industrial Classification (SIC) identification code, number of employees, annual sales, total square feet, fiscal year, etc. (*Muller et al. 2010*). The other five worksheets beginning with RECC and a number contained information regarding the specific recommendations given to the assessed manufacturer. Contents included: recommendation number and type, implementation status, implementation cost, energy saved, dollars saved, payback period, etc. (*Muller et al. 2010*). The IAC database requires the ASSESS and RECC# worksheets to be used in tandem, therefore, a unique identification code, as seen under ID Range in **Table 3.1** above, is provided in each worksheet which links the two.

Version 10.2 of The DOE Industrial Assessment Database Manual was used to define the data fields and coding schemes necessary to navigate the IAC database (*Muller et al. 2010*). Much of the pertinent information contained in the manual was spread through its multiple appendices, therefore, a simplified version of key variables are presented in **Tables 3.2** and **3.3** below.

Table 3.2: Key ASSESS variables.

Variable	Definition	Units
ID	Identifier used for linking ASSESS and RECC#	
FY	Fiscal year the assessment was performed	
SIC	Standard Industrial Classification code	
SALES	Annual sales for the site as reported by mfg.	U.S. Dollars
EMPLOYEES	Total number of employees on site as reported by mfg.	
PLANT_AREA	Total area used for production and office purposes	Sq. ft.
PRODUCTS	Principle product of the facility (in words)	
PRODHOURS	Annual production as reported by mfg.	Hours
USAGE_ELEC	Annual electrical consumption	kWh
USAGE_DEMD	Annual electrical consumption at peak load	kW-months/year
USAGE_NAT	Annual natural gas consumption	MMBtu
NAICS	North American Industrial Classification System code	

Table 3.3: Key RECC variables.

Variable	Definition	Units
ID	Identifier used for linking ASSESS and RECC#	
ARC2	Assessment Recommendation Code	
IMPSTATUS	Implementation as reported by mfg.	
IMPCOST	Implementation cost as reported by mfg. (may be estimated)	U.S. Dollars
PSAVED	Annual primary resource's savings	U.S. Dollars
SSAVED	Annual secondary resource's savings	U.S. Dollars
TSAVED	Annual tertiary resource's savings	U.S. Dollars
QSAVED	Annual quaternary resource's savings	U.S. Dollars
IC_CAPITAL	Capital (equip. & material) cost of recommendation	U.S. Dollars
IC_OTHER	Implementation costs which are not capital costs	U.S. Dollars
PAYBACK	Payback period for recommendation	Years

Lastly, version 9.1 of The ARC: Assessment Recommendation Code System, a separate IAC document, was used for obtaining the descriptions of the recommendation codes contained in the IAC database (*Muller & Kasten 2007*).

3.3 Data Preprocessing Methods

The downloaded IAC database Excel file was a 97-2003 version of MS Excel, therefore, the preprocessing began with saving the IAC database as a MS Excel 2013 file. All subsequent data preprocessing was performed in MS Excel 2013. Next, the five RECC# worksheets were combined into a single worksheet which will be referred to as RECC. After the basic formatting changes were complete, any irrelevant data was removed starting with manufacturer classification.

3.3.1 Manufacturer Classification

The IAC database classifies manufacturers by the main product produced by said manufacturer. There were three potentially useful variables contained in the IAC database: 1) SIC – the Standard Industrial Classification codes; 2) PRODUCTS – the principle product of the facility (in words); and 3) NAICS – the North American Industry Classification System codes. The

subjective nature of the written descriptions found in the PRODUCTS variable led to its removal from consideration which left the SIC and NAICS codes.

The North American Industrial Classification System (NAICS) is the current standard used by federal statistical agencies for analyzing data related to the U.S. business economy. The NAICS was implemented in 1997, replacing the Standard Industrial Classification (SIC) (*U.S. Census Bureau 2015*). The IAC database contains records of assessments conducted since 1981; therefore, some manufacturers are only classified under the SIC system. Exploration of the IAC database revealed that every assessed manufacturer had been given an SIC identification code, while NAICS codes first appear for only a few assessments conducted in 2002 and then become common in 2003 and beyond. Due to the missing NAICS values and the high variability of conversion between NAICS and SIC codes, only the SIC codes could be used to classify manufacturers objectively. Using the SIC manual maintained by the Occupational Safety and Health Administration (OSHA), any SIC entry that did not fall within Division D: Manufacturing or was incorrectly recorded were removed (*U.S. DOL 1987*).

3.3.2 Energy Recommendations

The second step in purging irrelevant data was the removal of non-energy recommendations. There were three main categories of recommendations provided in the IAC database: 1) energy management; 2) waste minimization/pollution prevention; and 3) direct productivity enhancements. These categories were represented by a 2.xxxx, 3.xxxx, or 4.xxx code, respectively. Using the ARC: Assessment Recommendation Code System, any ARC2 entry that did not have a 2.xxxx code or was incorrectly recorded were removed.

3.3.3 Variable Calculations and Inflation Adjustment

The next step in preprocessing was the calculation of monetary values followed by their adjustment for inflation. There are three variables which contain data concerning the capital investment required by the recommendation: 1) IC_CAPITAL – the equipment and materials cost; 2) IC_OTHER – implementation costs that are not capital costs; and 3) IMPCOST – the implementation cost as reported by the manufacturer (may be estimated). Investigation of these variables revealed that IMPCOST is equal to the addition of IC_CAPITAL and IC_OTHER, where applicable (see **Equation 3.1**). IC_CAPITAL and IC_OTHER are not consistently documented, therefore, the variable IMPCOST was used to determine implementation cost of the recommendation.

$$IMPCOST = IC_{CAPITAL} + IC_{OTHER}$$

Equation 3.1

Up to four variables represent the annual savings of any one recommendation: 1) PSAVED – dollar savings of the primary resource (greatest usage before recommendations); 2) SSAVED – dollar savings of the secondary resource (second greatest usage before recommendations); 3) TSAVED – dollar savings of the tertiary resource (second lowest usage before recommendations); and 4) QSAVED – dollar savings of the quaternary resource (least usage before recommendations). Each of these variables represent one resource stream and not all recommendations are documented out to the second, third, or fourth resource stream. The following is a written example of how these variables are related, as interpreted by data present in the database.

A manufacturer developed a repair/replace policy for their facility motors. The (PSAVED) savings were \$657.00 dollars annually in electrical consumption. However, this

recommendation also resulted in personnel changes that resulted in (SSAVED) savings of \$-180.00 dollars annually resulting in a net annual savings of \$495.00.

To obtain a net annual savings of the recommendation, a new variable called Saved was created by adding the variables PSAVED, SSAVED, TSAVED, and QSAVED (see **Equation 3.2**).

$$Saved = PSAVED + SSAVED + TSAVED + QSAVED \quad \text{Equation 3.2}$$

The variable PAYBACK represents the amount of time required to obtain the savings needed to negate the initial investment cost. Exploration of the database revealed that many values were missing for this variable. To solve this issue, a new variable called Payback was created by dividing the variable IMPCOST by the newly created Saved variable (see **Equation 3.3**). This method resulted in the same payback period in the cases where PAYBACK was documented, validating the methods used to obtain the cost, savings, and payback of the recommendations.

$$Payback = \frac{IMPCOST}{Saved} \quad \text{Equation 3.3}$$

Because the IAC database contains records from all years since initiation of program, 1981, the monetary values were adjusted for inflation, to the value of the 2014 U.S. Dollar, using Table 1.1.4. Price Indexes for Gross Domestic Product, (last revised on May 29, 2015), provided by the Bureau of Economic Analysis (*U.S. DOC 2015*) (see **Equation 3.4**).

$$\frac{Price(x)}{Price(y)} = \frac{Index(x)}{Index(y)} \quad \text{Equation 3.4}$$

3.3.4 Post Calculation Removals and Worksheet Merger

Once the calculations and inflation adjustment were complete additional irrelevant entries were removed. All entries found to have zero or less savings were removed, a total of 46, and all entries found to have negative costs were removed, a total of 27, as they were assumed to be a product of clerical errors. Next, the two worksheets, ASSESS and RECC were combined. To merge the manufacturer information in the ASSESS worksheet with the respective recommendation information in the RECC worksheet, a program code was created and executed in Excel's VBA editor. The program code is presented in **Appendix A**.

3.3.5 Final Preprocessing

Once the two worksheets had been successfully combined, the data was verified a final time. All blank entries found in IMPSTATUS were removed. It was found that the entry ID: SD0424's STATE variable was "a". SD is the abbreviation given to San Diego State University and that school has conducted assessments in Arizona, therefore "a" was changed to AZ. Similarly entry ID: IA0313's STATE variable was "NB". IA is the abbreviation given to Iowa State University and that school has conducted assessments in Nebraska, therefore "NB" was changed to NE. Once the obvious STATE entries were corrected any lower case entries for the variable were capitalized. Finally, it was found that entries ID: OR0446 and AR0095 had blank values for their PRODHOURS variable. Dr. Michael Muller, Professor of Mechanical and Aerospace Engineering at Rutgers University and Director of IAC database operations, was contacted about the meaning of variables with blank entries or zero as an entry. According to Dr. Muller's response, a blank or zero entry in non-monetary variables means the data was not available for some reason. Because JMP software would be used for statistics testing, all zeros found in non-monetary variables were made blank.

3.4 Additional Preparation Methods

3.4.1 Samples of Interest

All objectives, to some extent, required manufacturers to be grouped according to their manufacturer classification. The four groups of manufacturers are: 1) Non-wood – all manufacturers who do not produce wood products; 2) Wood – all manufacturers who produce wood products; 3) Primary – manufacturers who produce primary wood products; and 4) Secondary – manufacturers who produce secondary wood products. Using Division D – Major Groups 24 and 25 of the SIC manual maintained by the Occupational Safety and Health Administration (OSHA), the SIC codes for wood, primary, and secondary manufacturers were defined (see **Table 3.4**). All other SIC codes in Division D represent non-wood manufacturers (U.S. DOL 1987).

Table 3.4: Wood manufacturers with primary and secondary manufacturers distinguished.

Classification	SIC	SIC Title
Primary	2421	Sawmills and Planing Mills, General
	2426	Hardwood Dimension and Flooring Mills
	2429	Special Product Sawmills, NEC
	2435	Hardwood Veneer and Plywood
	2436	Softwood Veneer and Plywood
	2439	Structural Wood Members, NEC
	2493	Reconstituted Wood Products
	2499	Wood Products, NEC
Secondary	2431	Millwork
	2434	Wood Kitchen Cabinets
	2441	Nailed and Lock Corner Wood Boxes and Shook
	2448	Wood Pallets and Skids
	2449	Wood Containers, NEC
	2451	Mobile Homes
	2452	Prefabricated Wood Buildings and Components
	2511	Wood Household Furniture, Except Upholstered
	2512	Wood Household Furniture, Upholstered
	2517	Wood Television, Radio, Phonograph, and Sewing Machine Cabinets
	2521	Wood Office Furniture
	2541	Wood Office and Store Fixtures, Partitions, Shelving, and Lockers

3.4.2 Implementation Status

With the manufacturers grouped accordingly, focus shifted towards implementation rate of recommendations. The IAC database has four types of implementation status: 1) I – implemented; 2) P – pending; 3) N – not implemented; and 4) K – data excluded or unavailable (*Muller et al. 2010*). The data was further grouped as implemented, entries labeled I under the variable IMPSTATUS, and unimplemented, all entries labeled P, N, or K under the variable IMPSTATUS. As seen in **Table 3.5**, just over half of the energy recommendations given to wood manufacturers were implemented.

Table 3.5: *Number of recommendations for wood manufacturers by implementation status.*

IMPSTATUS	Entries
All Implementation Status	5,941
Implemented Only	3,037

Due to this finding, a deeper investigation of recommendation and implementation rates were conducted to determine how to proceed with the analysis. In **Table 3.6** the 30 most recommended and implemented recommendations for wood products manufacturers have been set side by side.

Table 3.6: Recommendation and implementation rate of recommendations among wood product manufacturers. Note: The recommendations above the bold horizontal line represent the top 30 recommendations. The blue tinted recommendations are a top 30 match in both rates, the red tinted recommendations are present in the top 30 implemented rate, and the green tinted recommendations are present in the top 30 recommended rate.

Rec. Rate	ARC2	Description	Imp. Rate	ARC2	Description
606	2.7142	Utilize higher efficiency lamps and/or ballasts	488	2.4236	Eliminate leaks in inert gas and compressed air lines/ valves
600	2.4236	Eliminate leaks in inert gas and compressed air lines/ valves	308	2.7142	Utilize higher efficiency lamps and/or ballasts
399	2.4111	Utilize energy-efficient belts and other improved mechanisms	254	2.4133	Use most efficient type of electric motors
385	2.4133	Use most efficient type of electric motors	204	2.4111	Utilize energy-efficient belts and other improved mechanisms
219	2.4221	Install compressor air intakes in coolest locations	113	2.4231	Reduce the pressure of compressed air to the minimum required
216	2.4231	Reduce the pressure of compressed air to the minimum required	107	2.4221	Install compressor air intakes in coolest locations
185	2.7143	Use more efficient light source	103	2.7143	Use more efficient light source
157	2.7135	Insulate bare equipment	66	2.3212	Optimize plant power factor
155	2.3212	Optimize plant power factor	56	2.6212	Turn off equipment during breaks, reduce operating time
107	2.2434	Recover heat from air compressor	55	2.1233	Analyze flue gas for proper air/fuel ratio
98	2.2511	Install occupancy sensors	49	2.7135	Insulate bare equipment
95	2.4141	Use or replace with energy efficient substitutes	49	2.2511	Install occupancy sensors
93	2.6218	Turn off equipment when not in use	48	2.2131	Insulate steam / hot water lines
90	2.1233	Analyze flue gas for proper air/fuel ratio	47	2.6218	Turn off equipment when not in use
90	2.6212	Turn off equipment during breaks, reduce operating time	45	2.7111	Reduce illumination to minimum necessary levels
88	2.7261	Install timers and/or thermostats	42	2.4232	Eliminate or reduce compressed air used for cooling, agitating liquids, moving product, or drying
84	2.2131	Insulate steam / hot water lines	40	2.7124	Make a practice of turning off lights when not needed
82	2.4232	Eliminate or reduce compressed air used for cooling, agitating liquids, moving product, or drying	39	2.2434	Recover heat from air compressor
81	2.7111	Reduce illumination to minimum necessary levels	38	2.8121	Apply for tax-free status for energy purchases
68	2.7124	Make a practice of turning off lights when not needed	34	2.7261	Install timers and/or thermostats
65	2.7134	Use photocell controls	32	2.4224	Upgrade controls on compressors
65	2.4224	Upgrade controls on compressors	32	2.6232	Install set-back timers
60	2.4322	Use synthetic lubricant	30	2.7134	Use photocell controls
56	2.3131	Reschedule plant operations or reduce load to avoid peaks	27	2.4314	Use multiple speed motors or AFD for variable pump, blower and compressor loads

53	2.1311	Replace electrically-operated equipment with fossil fuel equipment	27	2.4322	Use synthetic lubricant
51	2.6232	Install set-back timers	27	2.4141	Use or replace with energy efficient substitutes
49	2.4314	Use multiple speed motors or AFD for variable pump, blower and compressor loads	26	2.4151	Develop a repair/replace policy
48	2.3211	Use power factor controllers	22	2.3131	Reschedule plant operations or reduce load to avoid peaks
46	2.8121	Apply for tax-free status for energy purchases	21	2.3211	Use power factor controllers
42	2.8114	Change rate schedules or other changes in utility service	19	2.4312	Improve lubrication practices
35	2.7121	Utilize daylight whenever possible in lieu of artificial light	16	2.8114	Change rate schedules or other changes in utility service
35	2.4312	Improve lubrication practices	16	2.7112	Reduce exterior illumination to minimum safe level
34	2.4151	Develop a repair/replace policy	15	2.2133	Repair leaks in lines and valves
34	2.6231	Utilize controls to operate equipment only when needed	15	2.7121	Utilize daylight whenever possible in lieu of artificial light
32	2.2437	Recover waste heat from equipment	14	2.4226	Use / purchase optimum sized compressor
31	2.3414	Burn waste to produce steam to drive a steam turbine generator set and use steam exhaust for heat	13	2.1311	Replace electrically-operated equipment with fossil fuel equipment

As seen in **Table 3.6**, 28 recommendations fall into the top 30 range in both lists, while the recommendations that do not still fall closely to the top 30. Because the goal of this research is to identify the recommendations which have the greatest impact on the wood products industry and due to the similarity of results between recommendation rate and implementation rate, further statistical analysis was performed on implemented recommendations.

3.4.3 Final Preparation

The final step of data preparation was formatting for statistical analysis. The top 30 most implemented recommendations for each manufacturing group: non-wood, wood, primary, and secondary were isolated and saved to a new worksheet each named accordingly.

3.5 Objective 1 Methods

Objective 1 was to identify and rank energy recommendations given to wood products manufacturers by implementation cost, savings, payback period, and implementation frequency. The purpose of this objective was to determine which energy recommendations have the greatest impact on the wood products industry. Criteria such as cost, savings, payback period, and implementation frequency were chosen due to their usefulness for interested manufacturers to evaluate potential energy-saving practices based on their own needs.

3.5.1 Identification & Ranking

The top 30 recommendations given to Wood manufacturers in the IAC database were ranked by: 1) least cost; 2) greatest savings; 3) shortest payback period; and 4) most frequently implemented.

3.6 Objective 2 Methods

Objective 2 was to compare implemented energy recommendations by cost, savings, and payback criteria between wood and non-wood manufacturers and between primary and secondary wood manufacturers. The purpose of this objective was to determine if any energy-saving practices were inherently better for a particular manufacturing group based on the differences in cost, savings, and payback periods.

3.6.1 Energy Recommendation Comparisons between Manufacturing Groups

The 30 most frequently implemented recommendations for wood products manufacturers, non-wood products manufacturers, primary wood products manufacturers, and secondary wood products manufacturers were collected and uploaded into JMP Pro 11 where all subsequent analysis took place.

Next, the Cost, Saved, and Payback variables (response variables) were tested for normality to determine if an ANOVA test would have been a valid method for comparing the manufacturing groups. Using the Kolmogorov-Smirnov-Lilliefors (KSL) test, the response variables of the manufacturing groups were tested for normality, the results of which concluded that the response variable data was not drawn from a normal distribution (see **Table 3.7**). Screen shots of the KSL test results are provided in **Appendix B**.

Table 3.7: KSL, goodness of fit tests results.

Manufacturing Group	Response Variable	p-value
Wood vs Non-wood	Cost	<0.0100
Wood vs Non-wood	Savings	<0.0100
Wood vs Non-wood	Payback Period	<0.0100
Primary vs Secondary	Cost	<0.0100
Primary vs Secondary	Savings	<0.0100
Primary vs Secondary	Payback Period	<0.0100

It was determined that an ANOVA test would not be a valid method for comparing the manufacturing groups due to the lack of normality displayed by the response variables and the purposive methods used to select the data. Therefore, analysis proceeded using the non-parametric Wilcoxon rank-sum test which tests whether the rank-sums of data are similar across two groups.

3.6.2 Exploring Differences

For energy recommendations that were significantly different between the manufacturing groups; a secondary analysis was performed to discover which variables influenced the response variables. The results would be used to explain what contributed to the detected difference.

Explanatory variables selected for the secondary analysis were: EMPLOYEES, PLANT_AREA, PRODHOURS, SALES, USAGE_ELEC, USAGE_DEMD, and USAGE_NAT.

These variables were chosen from the IAC database because they were actual data that described the manufacturing plants and would have had some impact on energy consumed by the manufacturer and could be used to explain the differences found from the Wilcoxon tests.

Backward regression was the method chosen to identify which explanatory variables influenced the response variables because backward regression begins with all potential explanatory variables included in the model then one by one removes the explanatory variables that contributes least until all remaining contribute significantly to the response variable (*Ratner 2010*).

3.7 Objective 3 Methods

Objective 3 was to identify energy recommendations from the IAC database, implemented by wood products manufacturers, which incorporate lean manufacturing practices or principles. The purpose of this objective was to impartially identify lean-energy practices and evaluate their results for wood products manufacturers.

3.7.1 Lean Tool Identification

Lean manufacturing is multi-dimensional. It is based in culture, principles, and practices; all of which contribute to waste reduction and/or increased productivity through human resources, assets, and time optimization (*Becker 2001; Sharma et al. 2011*). Connecting metrics to lean philosophy and principles and measuring their impacts is a difficult endeavor. Due to these constraints, lean tools are the dominant method of quantifying various aspects of lean manufacturing (*Narasimhan et al. 2006; Shah & Ward 2007; Womack 2007*). There are no known official standards for defining what constitutes a lean tool, therefore, lean tools were identified by a list constructed by Kirby and Green (2003) (see **Table 3.8**). Kirby and Green's (2003) definition of a lean tool met the following criteria:

- 1) "Improves the rate of flow (such that it meets the expected rate of the customer); either of information, products, or materials."
- 2) "Creates flexibility, (increases the cross-sectional dimensions of the value stream) in capacity or order fulfillment."
- 3) "Reduces time in production process (thereby reducing the length of the stream)."
- 4) "Facilitates the continuous improvement of the production system in any of these three ways."
- 5) "Be cited in at least three sources within the literature on lean production (or JIT, lean manufacturing, and time-based manufacturing)."

A common figure in lean literature is the "lean house" or "TPM house" (see **Figure 3.1**). Some may be more familiar with these lean principles, so the Kirby and Green (2003) lean tools have been associated with one of the "bricks" of the lean house for simplification (see **Table 3.8**).

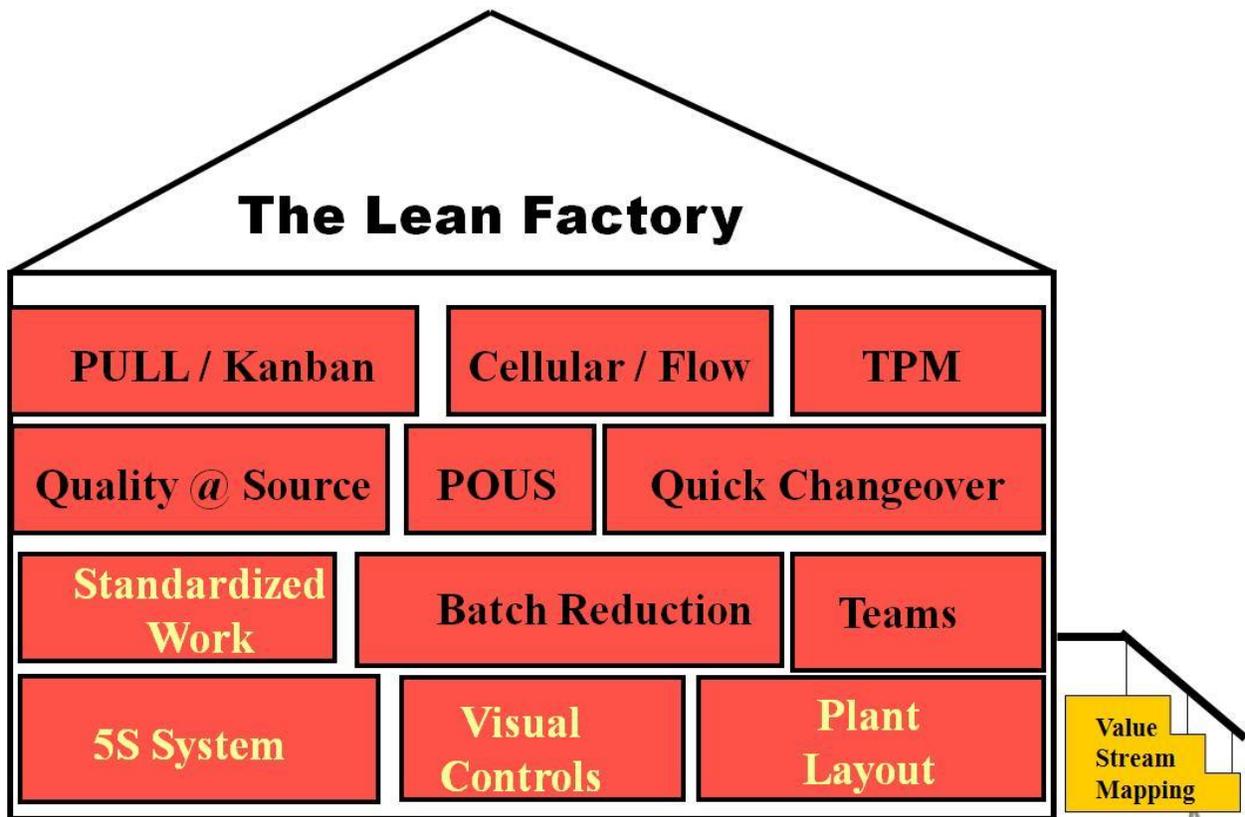


Figure 3.1: Example of the lean house. Source: (Sustainable Innovation Management 2012).

Table 3.8: Lean tools as identified by Kirby and Green (2003) and their association in the lean house as presented in Figure 3.1.

Lean House	Lean Tool	Definition
Plant Layout	Flow Cells	Manufacturing or assembling in a layout in which all (or most) of the parts and machines necessary to complete a part or assembly are in close proximity of one another.
Visual Controls	Visual Controls	Use of visual signs and signals to communicate the status of an operation or production line. Visual controls include any graphical marking or other visual signal that serves as a quick and complete communication to an operator or manager.
5s System	5s	Five Japanese words for creating and maintaining a clean, organized work environment. Seiri (sifting), Seiton (Sorting), Seiso (Sweeping), Seiketsu (Standardize), Shitsuke (Sustain)
Teams	Lean “Kaizen” Events	A focused improvement event during which a cross-functional team of operators, engineers, etc. spends several days analyzing and implementing improvements to a specific work area.
	Team-Based Problem Solving	Solutions to problems that arise in the production process are generated at daily or weekly meetings facilitated by the operators affected.

Batch Reduction	Mixed-Model Production	The ability to make several products on the same line in a random or sequenced order without a massive amount of changeover time.
	Smoothed Production Schedule	Development and use of a consistent and repetitive schedule across product offerings.
Standardized Work	Standard Work	A series of tasks grouped together such that the sum of the individual task times is less than or equal to the takt time.
	Method Sheets	Graphical depiction of the work instructions for a group of tasks at a particular workstation.
Quick Changeover	Set-up Reduction	An organized, scientific approach to reducing the amount of time it takes to change a machine from producing one product to another.
POUS	Point-of-Use Material Storage	The preparation of work areas for direct presentation of supplied materials.
Quality at Source	Autonomation	Designing a machine to stop automatically when it detects an error in the production process.
	Mistake-Proofing	The use of fixturing and tooling to eliminate or reduce the possibility of errors being made in the assembly of the product.
	Self-Check Inspection	Work is inspected before passing it on to the next station.
	Successive Check Inspection	Work is inspected at the succeeding workstation.
	Line Stop	Giving the operator the ability to stop an assembly line or cell flow when an error is detected in the process.
	Design-of-Experiments	Use of statistical tools to analyze a process to determine the variables that are affecting specific outcomes.
	Root Cause Analysis	Problem solving technique in which the team or individual attempts to drive down to the fundamental cause of the problem in order to keep it from recurring.
	Statistical Process Control	Use of control charts to study processes and determine when the process is out of control.
TPM	Total Productive Maintenance	A maintenance strategy, which incorporates the operators in daily maintenance activities, such as, checking for vibrations, oil and lubrication, etc.
	Reliability-Centered Maintenance	A maintenance strategy in which a detailed Failure Modes and Effects Analysis are done for each critical piece of machinery, and explicit maintenance strategies are created.
	Preventive Maintenance	A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.
	Predictive Maintenance	A maintenance strategy in which machines are analyzed with special equipment that can predict machine failure based on vibration, lubrication, temperature, and other analyses, with an emphasis on planned maintenance.
Cellular/Flow	One-Piece Flow	The ability to produce one part at a station at a time. This is contrasted with batch production, in which more than one part is processed at a station before moving to the next station.
	Cross-Trained Workforce	Workers are trained and scheduled to do multiple jobs, thereby increasing the flexibility of the workforce to move to different cells and lines dependent upon the demand fluctuations.
Pull/Kanban	Production to Takt time	Takt time is the rate of customer demand for the part or product being made. Production to takt time refers to the balancing of work activities such that the average production rate is equivalent to takt time, no more no less.

Pull Production
Scheduling

As materials are consumed at a downstream operation, signals are sent back to previous steps in the production process to pull forward sufficient materials to replenish only those materials that have been consumed.

3.7.2 Recommendations Implemented by the Wood Products Industry

Using the IAC database, wood products manufacturers were isolated and all unimplemented recommendations were removed. Next, duplicates of the implemented recommendations were removed leaving 192 unique recommendations that have been implemented by wood products manufacturers (see **Appendix C**).

3.7.3 Lean-Energy Recommendation Identification

To identify the energy recommendations implemented by wood products manufacturers that incorporate lean practices or principles an inductive reasoning approach was used. According to Klauer and Phye (2008) inductive reasoning is a comparison method where objects, attributes of objects, or relationships between objects are scanned for commonality and/or diversity aimed at detecting generalizations, rules, or regularities. Following this inductive reasoning approach, all 192 unique energy recommendations implemented by wood products manufacturers and the 27 lean tools, as identified by Kirby and Green (2003), were searched for linguistic commonalities. Energy recommendations that matched word-for-word with a lean tool's title were identified as "specifically lean", recommendations which matched the language of a lean tool's definition were identified as "descriptively lean", and those that could be interpreted as lean, given certain circumstances, were identified as "arguably lean". Lastly, a secondary approach for identifying lean-based using waste elimination was conducted. Energy recommendations that do not affect the conservation or efficiency of energy were identified as non-lean recommendations.

3.8 Objective 4 Methods

Objective 4 was to investigate energy consumption, energy management practices, and perspectives of wood product manufacturers regarding energy management. The purpose of this objective was to interview wood products manufactures to obtain information which could be related back to best-practices described in the literature and to probe the perspectives of the manufactures, specifically looking for where they are informed about energy management and which barriers most impede the implementation of energy management.

3.8.1 Comparative Case Study & Interview Method

A comparative case study was the chosen method for investigating energy and energy management of wood product manufacturers, as opposed to a survey, because according to Dul et al. (2007); a comparative case study is a study in which inquiries of real life context are obtained from a small number of cases and analyzed in a qualitative manner. Case studies are different from surveys in two ways; 1) a survey examines a population, while a case study examines one ‘case’ and 2) a survey draws conclusions on a quantitative basis, while a case study draws conclusions on a qualitative basis (Dul et al. 2007).

A modified style of telephone interview was the chosen method for conducting the case studies. Typical telephone interviews lack visual materials and subsequently must be less complex than other types of interviews (Rea & Parker 2014). To address these disadvantages, each respondent was emailed a Microsoft Word and PDF file format copy of a recruitment letter (**Appendix D**) and the questionnaire (**Appendix E**) to read over prior and during the phone interview.

3.8.2 Questionnaire Development

The questionnaire was developed to address three main goals: 1) obtain information for comparison to the IAC database; 2) obtain information about energy saving practices; and 3) obtain information not readily available in the literature. Questions 1-9 were designed for use in comparing responses to the IAC database, questions 10-17 were developed from common energy saving practices and principles found in literature and used to evaluate energy saving practices, and questions 18-20 were designed to obtain information about the perspective of energy management among manufacturers; a topic not found in the literature. The questionnaire was reviewed by faculty at Virginia Tech and an industry specialist at the USDA Forest Service.

3.8.3 Target Population and Sample

The population of interest for this research were wood product or wood furniture product manufacturers operating in the Commonwealth of Virginia. Potential interviewees were collected from The Forest Products Network, an online forest products manufacturing directory (SGSF 2015). The researchers wanted to interview at least two primary and two secondary wood product manufactures, therefore, purposive sampling was the method used for choosing which manufacturers were contacted. A total of eleven wood products manufacturers were contacted about participation, five wood products manufacturers agreed to be interviewed.

3.8.4 Data Collection

The interviewer was knowledgeable of the scope and purpose of the project, had completed training in human subject protection, and understood telephone interview procedures described in Rea and Parker (2014). Phone calls, emails, or visits were made to each company soliciting recruitment. When a manufacturer agreed to participate in an interview, the questionnaire was

emailed to the respondent and a time was scheduled to conduct the phone interview. Respondents were encouraged to read over the questions prior to and during the interview process.

CHAPTER 4 – DATABASE ANALYSIS (DESCRIPTIVE STATISTICS)

4.1 Introduction

This chapter focuses on the identity and rank of energy recommendations given to wood products manufacturers by implementation cost, savings, payback period, and implementation frequency; objective 1.

4.2 Results and Discussion

The following tables represent the top 30 recommendations given to wood products manufacturers by least implementation cost (**Table 4.1**), greatest annual savings (**Table 4.2**), shortest payback period (**Table 4.3**), and frequency of implementation (**Table 4.4**).

Table 4.1: Top 30 least cost recommendations implemented by wood manufacturers.

ARC2	Description	Imp. Freq.	Avg. Cost	Avg. Saved Per Year	Avg. Payback
2.1122	Re-size charging openings or add a movable door on equipment	1	\$0.00	\$2,527.14	0.00
2.2153	Close off unneeded steam lines	3	\$0.00	\$2,207.09	0.00
2.2163	Use minimum steam operating pressure	1	\$0.00	\$2,709.13	0.00
2.2627	Use multiple-effect evaporators	1	\$0.00	\$1,534.05	0.00
2.3134	Shift from daytime to nighttime operation	1	\$0.00	\$1,149.98	0.00
2.3135	Schedule routine maintenance during non-operating periods	1	\$0.00	\$874.97	0.00
2.3137	Use power during off-peak periods	1	\$0.00	\$241,015.82	0.00
2.4313	Provide proper maintenance / of motor driven equipment	1	\$0.00	\$2,818.64	0.00
2.5194	Redesign process	1	\$0.00	\$11,572.09	0.00
2.6213	Turn off steam / hot water lines leading to space heating units	1	\$0.00	\$4,878.31	0.00
2.6222	Use drying oven (batch type) on alternate days or other optimum schedule to run equipment with full loads	1	\$0.00	\$6,444.93	0.00
2.7225	Close outdoor air dampers during warm-up / cool-down periods	1	\$0.00	\$11,349.14	0.00
2.7314	Reduce ventilation air	1	\$0.00	\$7,761.23	0.00
2.7316	Centralize control of exhaust fans to ensure their shutdown, or establish program to ensure manual shutdown	1	\$0.00	\$3,606.92	0.00
2.8123	Pay utility bills on time	8	\$0.00	\$2,798.53	0.00
2.8223	Add air shields to trucks to increase fuel mileage	1	\$0.00	\$1,941.94	0.00
2.1223	Install smaller boiler (increase high fire duty cycle)	1	\$11.77	\$7,413.52	0.00
2.2625	Chill water to the highest temperature possible	2	\$26.46	\$5,747.07	0.01
2.6214	Shut off pilots in standby equipment	8	\$78.20	\$1,078.09	0.11
2.6124	Establish equipment maintenance schedule	1	\$97.47	\$963.04	0.10
2.6121	Reduce hot water temperature to the minimum required	6	\$126.58	\$1,528.75	0.67
2.6123	Remove unneeded service lines to eliminate potential leaks	1	\$171.53	\$1,188.38	0.14
2.2711	Utilize outside air instead of conditioned air for drying	1	\$200.19	\$235.52	0.85
2.7223	Condition smallest space necessary	2	\$299.89	\$5,442.99	0.05
2.4312	Improve lubrication practices	19	\$325.37	\$3,330.56	0.33
2.7221	Lower temperature during the winter season and vice-versa	8	\$359.90	\$4,427.21	0.31
2.7444	Close holes and openings in building such as broken windows	5	\$432.73	\$887.35	0.86
2.2622	Replace existing chiller with high efficiency model	1	\$444.59	\$102.41	4.34
2.8111	Check for accuracy of utility meters	3	\$452.33	\$7,634.90	0.15
2.7441	Replace broken windows and/or window sash	3	\$464.93	\$11,082.94	0.43

Table 4.2: Top 30 greastest savings recommendations implemented by wood manufacturers.

ARC2	Description	Imp. Freq.	Avg. Cost	Avg. Saved Per Year	Avg. Payback
2.3411	Replace electric motors with back pressure steam turbines and use exhaust steam for process heat	2	\$3,606,766.90	\$1,223,439.47	1.59
2.2162	Reduce excess steam bleeding	1	\$31,158.41	\$610,259.79	0.05
2.3414	Burn waste to produce steam to drive a steam turbine generator set and use steam exhaust for heat	5	\$1,844,214.61	\$351,628.87	3.91
2.3137	Use power during off-peak periods	1	\$0.00	\$241,015.82	0.00
2.5195	Change product design to reduce energy requirements	1	\$211,357.21	\$192,243.67	1.10
2.2126	Lower operating pressure of condenser (steam)	1	\$52,422.20	\$186,984.76	0.28
2.3192	Use fossil fuel powered generator during peak demand periods	2	\$651,518.65	\$136,732.77	4.00
2.8211	Consolidate freight shipments and/or deliveries	1	\$143,673.82	\$134,694.20	1.07
2.4322	Use or replace with energy efficient substitutes	27	\$32,650.31	\$91,779.24	1.33
2.1336	Install equipment to utilize waste fuel	3	\$212,758.12	\$91,554.25	2.30
2.3415	Use a fossil fuel engine to cogenerate electricity or motive power; and utilize heat	1	\$112,938.76	\$82,210.61	1.37
2.2135	Repair and eliminate steam leaks	13	\$5,617.78	\$73,847.37	1.89
2.2127	Flash condensate to produce lower pressure steam	2	\$35,492.28	\$70,332.30	0.53
2.2445	Recover heat from exhausted steam	2	\$9,577.36	\$63,068.80	0.19
2.1331	Burn a less expensive grade of fuel	5	\$25,443.59	\$62,842.87	0.87
2.4325	Upgrade conveyors	2	\$11,508.03	\$61,402.00	0.63
2.1116	Improve combustion control capability	1	\$50,285.84	\$58,187.90	0.86
2.3412	Use waste heat to produce steam to drive a steam turbine generator	1	\$188,515.52	\$55,999.30	3.37
2.1232	Keep boiler tubes clean	9	\$15,657.11	\$55,504.58	0.46
2.3321	Use steam pressure reduction to generate power	1	\$37,896.65	\$50,167.37	0.76
2.2121	Increase amount of condensate returned	7	\$151,502.59	\$48,929.38	1.48
2.7492	Use proper thickness of insulation on building envelope	4	\$20,929.99	\$47,289.62	1.86
2.2426	Use waste heat from flue gases to heat space conditioning air	1	\$13,227.50	\$44,822.71	0.30
2.4222	Install adequate dryers on air lines to eliminate blowdown	6	\$24,304.29	\$43,859.20	2.63
2.2425	Use flue gases to heat process or service water	1	\$83,406.40	\$43,734.20	1.91
2.1133	Adjust burners for efficient operation	6	\$898.65	\$40,764.45	0.34
2.2441	Preheat boiler makeup water with waste process heat	2	\$8,481.94	\$38,049.74	0.58
2.2512	Increase insulation thickness	2	\$56,349.48	\$34,834.79	0.92
2.1221	Replace obsolete burners with more efficient ones	3	\$41,357.94	\$34,441.63	1.47
2.4141	Use multiple speed motors or AFD for variable pump, blower and compressor loads	27	\$53,037.67	\$33,859.93	1.68

Table 4.3: Top 30 shortest payback recommendations implemented by wood manufacturers.

ARC2	Description	Imp. Freq.	Avg. Cost	Avg. Saved Per Year	Avg. Payback
2.1122	Re-size charging openings or add a movable door on equipment	1	\$0.00	\$2,527.14	0.00
2.2153	Close off unneeded steam lines	3	\$0.00	\$2,207.09	0.00
2.2163	Use minimum steam operating pressure	1	\$0.00	\$2,709.13	0.00
2.2627	Use multiple-effect evaporators	1	\$0.00	\$1,534.05	0.00
2.3134	Shift from daytime to nighttime operation	1	\$0.00	\$1,149.98	0.00
2.3135	Schedule routine maintenance during non-operating periods	1	\$0.00	\$874.97	0.00
2.3137	Use power during off-peak periods	1	\$0.00	\$241,015.82	0.00
2.4313	Provide proper maintenance / of motor driven equipment	1	\$0.00	\$2,818.64	0.00
2.5194	Redesign process	1	\$0.00	\$11,572.09	0.00
2.6213	Turn off steam / hot water lines leading to space heating units	1	\$0.00	\$4,878.31	0.00
2.6222	Use drying oven (batch type) on alternate days or other optimum schedule to run equipment with full loads	1	\$0.00	\$6,444.93	0.00
2.7225	Close outdoor air dampers during warm-up / cool-down periods	1	\$0.00	\$11,349.14	0.00
2.7314	Reduce ventilation air	1	\$0.00	\$7,761.23	0.00
2.7316	Centralize control of exhaust fans to ensure their shutdown, or establish program to ensure manual shutdown	1	\$0.00	\$3,606.92	0.00
2.8123	Pay utility bills on time	8	\$0.00	\$2,798.53	0.00
2.8223	Add air shields to trucks to increase fuel mileage	1	\$0.00	\$1,941.94	0.00
2.1223	Install smaller boiler (increase high fire duty cycle)	1	\$11.77	\$7,413.52	0.00
2.2625	Chill water to the highest temperature possible	2	\$26.46	\$5,747.07	0.01
2.2162	Reduce excess steam bleeding	1	\$31,158.41	\$610,259.79	0.05
2.8113	Purchase gas directly from a contract gas supplier	3	\$576.74	\$12,188.54	0.05
2.7223	Condition smallest space necessary	2	\$299.89	\$5,442.99	0.05
2.1321	Replace fossil fuel equipment with electrical equipment	2	\$514.96	\$16,353.41	0.07
2.6124	Establish equipment maintenance schedule	1	\$97.47	\$963.04	0.10
2.7141	Lower light fixtures in high ceiling areas	2	\$870.05	\$8,627.91	0.11
2.6214	Shut off pilots in standby equipment	8	\$78.20	\$1,078.09	0.11
2.2522	Isolate hot or cold equipment	1	\$1,251.01	\$9,612.75	0.13
2.6123	Remove unneeded service lines to eliminate potential leaks	1	\$171.53	\$1,188.38	0.14
2.8111	Check for accuracy of utility meters	3	\$452.33	\$7,634.90	0.15
2.1222	Install turbulators	1	\$2,246.84	\$13,031.65	0.17
2.1132	Repair faulty louvers and dampers	1	\$548.91	\$2,870.79	0.19

Table 4.4: Top 30 most frequently implemented recommendations by wood manufacturers.

ARC2	Description	Imp. Freq.	Avg. Cost	Avg. Saved Per Year	Avg. Payback
2.4236	Eliminate leaks in inert gas and compressed air lines/ valves	488	\$2,975.22	\$7,911.86	0.46
2.7142	Utilize higher efficiency lamps and/or ballasts	308	\$9,900.59	\$5,121.25	2.79
2.4133	Use most efficient type of electric motors	254	\$17,717.78	\$5,961.40	3.56
2.4111	Utilize energy-efficient belts and other improved mechanisms	204	\$3,024.00	\$5,016.05	0.70
2.4231	Reduce the pressure of compressed air to the minimum required	113	\$1,388.34	\$3,510.72	0.29
2.4221	Install compressor air intakes in coolest locations	107	\$698.36	\$1,724.93	0.75
2.7143	Use more efficient light source	103	\$11,926.14	\$6,731.55	2.08
2.3212	Optimize plant power factor	66	\$17,810.85	\$13,686.12	1.69
2.6212	Turn off equipment during breaks, reduce operating time	56	\$886.26	\$4,819.18	0.28
2.1233	Analyze flue gas for proper air/fuel ratio	55	\$5,415.09	\$18,178.42	0.75
2.2511	Insulate bare equipment	49	\$3,644.21	\$6,811.90	1.89
2.7135	Install occupancy sensors	49	\$7,388.21	\$3,994.08	1.73
2.2131	Insulate steam / hot water lines	48	\$5,569.23	\$4,417.00	1.34
2.6218	Turn off equipment when not in use	47	\$2,299.31	\$5,635.00	0.46
2.7111	Reduce illumination to minimum necessary levels	45	\$2,110.56	\$6,060.02	0.43
2.4232	Eliminate or reduce compressed air used for cooling, agitating liquids, moving product, or drying	42	\$1,838.34	\$7,551.45	0.75
2.7124	Make a practice of turning off lights when not needed	40	\$1,650.31	\$6,286.86	0.20
2.2434	Recover heat from air compressor	39	\$2,104.20	\$3,040.32	1.15
2.8121	Apply for tax-free status for energy purchases	38	\$1,666.24	\$7,150.98	0.31
2.7261	Install timers and/or thermostats	34	\$1,225.66	\$6,965.82	0.47
2.4224	Upgrade controls on compressors	32	\$18,278.73	\$17,430.57	1.07
2.6232	Install set-back timers	32	\$1,621.34	\$8,198.67	0.30
2.7134	Use photocell controls	30	\$1,614.76	\$2,281.47	0.84
2.4141	Use multiple speed motors or AFD for variable pump, blower and compressor loads	27	\$53,037.67	\$33,859.93	1.68
2.4314	Use synthetic lubricant	27	\$586.64	\$1,927.93	0.49
2.4322	Use or replace with energy efficient substitutes	27	\$32,650.31	\$91,779.24	1.33
2.4151	Develop a repair/replace policy	26	\$4,502.08	\$4,995.05	1.40
2.3131	Reschedule plant operations or reduce load to avoid peaks	22	\$1,356.63	\$14,897.05	0.36
2.3211	Use power factor controllers	21	\$21,241.64	\$15,278.32	1.51
2.4312	Improve lubrication practices	19	\$325.37	\$3,330.56	0.33

Upon visual inspection, the first noticeable findings were the low implementation rates among the least cost, greatest savings, and shortest payback rankings. The average number of times a recommendation was implemented by wood products manufacturers was 16 from a total 3,037. Of the 30 recommendations present in **Table 4.1** (least cost ranking), 29 were implemented less than the average, 19 of which were implemented only once. Of the 30 recommendations present in **Table 4.2** (greatest savings ranking), 28 were implemented less than the average, 11 of which were implemented only once. Of the 30 recommendations present in **Table 4.3** (shortest payback ranking), each recommendation was implemented less than the average, 21 of which were implemented only once.

Second, it appeared that no specific recommendation was present in each of the four rankings which suggests that wood manufacturers may not have implemented recommendations specifically based on lowest cost, greatest savings, or shortest payback period. For example, recommendation 2.4236 (Eliminate leaks in inert gas and compressed air lines/valves) is the most frequently implemented recommendation among wood product manufacturers, however, it is not present among the rankings based on least cost, greatest savings, or shortest payback period. To confirm this visual assumption, recommendation(s) which were present in multiple rankings were identified and compiled into **Tables 4.5-4.9** according to the rankings they were present in.

Table 4.5: *Present in least cost, greatest savings, and shortest payback rankings.*

ARC2	Description	Imp. Freq.	Avg. Cost	Avg. Saved Per Year	Avg. Payback
2.3137	Use power during off-peak periods	1	\$0.00	\$241,015.82	0.00

Table 4.6: Present in least cost and shortest payback rankings.

ARC2	Description	Imp. Freq.	Avg. Cost	Avg. Saved Per Year	Avg. Payback
2.1122	Re-size charging openings or add a movable door on equipment	1	\$0.00	\$2,527.14	0.00
2.1223	Install smaller boiler (increase high fire duty cycle)	1	\$11.77	\$7,413.52	0.00
2.2153	Close off unneeded steam lines	3	\$0.00	\$2,207.09	0.00
2.2163	Use minimum steam operating pressure	1	\$0.00	\$2,709.13	0.00
2.2625	Chill water to the highest temperature possible	2	\$26.46	\$5,747.07	0.01
2.2627	Use multiple-effect evaporators	1	\$0.00	\$1,534.05	0.00
2.3134	Shift from daytime to nighttime operation	1	\$0.00	\$1,149.98	0.00
2.3135	Schedule routine maintenance during non-operating periods	1	\$0.00	\$874.97	0.00
2.4313	Provide proper maintenance / of motor driven equipment	1	\$0.00	\$2,818.64	0.00
2.5194	Redesign process	1	\$0.00	\$11,572.09	0.00
2.6123	Remove unneeded service lines to eliminate potential leaks	1	\$171.53	\$1,188.38	0.14
2.6124	Establish equipment maintenance schedule	1	\$97.47	\$963.04	0.10
2.6213	Turn off steam / hot water lines leading to space heating units	1	\$0.00	\$4,878.31	0.00
2.6214	Shut off pilots in standby equipment	8	\$78.20	\$1,078.09	0.11
2.6222	Use drying oven (batch type) on alternate days or other optimum schedule to run equipment with full loads	1	\$0.00	\$6,444.93	0.00
2.7223	Condition smallest space necessary	2	\$299.89	\$5,442.99	0.05
2.7225	Close outdoor air dampers during warm-up / cool-down periods	1	\$0.00	\$11,349.14	0.00
2.7314	Reduce ventilation air	1	\$0.00	\$7,761.23	0.00
2.7316	Centralize control of exhaust fans to ensure their shutdown, or establish program to ensure manual shutdown	1	\$0.00	\$3,606.92	0.00
2.8111	Check for accuracy of utility meters	3	\$452.33	\$7,634.90	0.15
2.8123	Pay utility bills on time	8	\$0.00	\$2,798.53	0.00
2.8223	Add air shields to trucks to increase fuel mileage	1	\$0.00	\$1,941.94	0.00

Table 4.7: Present in greatest savings and shortest payback rankings.

ARC2	Description	Imp. Freq.	Avg. Cost	Avg. Saved Per Year	Avg. Payback
2.2162	Reduce excess steam bleeding	1	\$31,158.41	\$610,259.79	0.05

Table 4.8: Present in most frequently implemented and least cost rankings.

ARC2	Description	Imp. Freq.	Avg. Cost	Avg. Saved Per Year	Avg. Payback
2.4312	Improve lubrication practices	19	\$325.37	\$3,330.56	0.33

Table 4.9: Present in most frequently implemented and greatest savings rankings.

ARC2	Description	Imp. Freq.	Avg. Cost	Avg. Saved Per Year	Avg. Payback
2.4141	Use multiple speed motors or AFD for variable pump, blower and compressor loads	27	\$53,037.67	\$33,859.93	1.68
2.4322	Use or replace with energy efficient substitutes	27	\$32,650.31	\$91,779.24	1.33

As seen in **Table 4.5**, recommendation 2.3137 (Use power during off-peak periods) appeared most often, as it was present in three rankings: least cost, greatest savings, and shortest payback period. This recommendation is unique among the majority of recommendations present in the IAC database as it does not reduce energy consumption, but aims to reduce the price of the energy consumed. Even though this recommendation was implemented once, the expected results of its implementation by other wood products manufacturers should yield similar results as the practice of using power during off-peak periods can provide significant gains as little to no cost (Muller et al. 2001).

From **Table 4.6** we find that 22 recommendations were present in both the least cost and shortest payback period rankings; this is unsurprising as payback period is a function of cost divided by savings. Looking back at **Table 4.1** (least cost ranking) and **Table 4.3** (shortest payback ranking) we see that the first 18 recommendations are the same for both.

What is interesting, based on the findings presented in **Tables 4.5-4.9**, is how no recommendation was present in each of the four rankings, suggesting that wood products manufacturers were not focused on implementing recommendations specifically based on least cost, greatest savings, or shortest payback period. This idea is further supported by the low frequency of implementation of recommendations based purely on cost, savings, and payback period. Furthermore, when inspecting the recommendations in **Table 4.4** (most frequently

implemented ranking) we find that they were not the cheapest to implement, did not produce the largest returns, and did not have the shortest payback periods.

If the wood products manufacturers were not choosing to implement recommendations based on costs, savings, or payback periods they must have had other reasons why they chose to implement what they did. To discover those reasons, it was decided to examine the recommendations by groups rather than individually as no clear trends were identified at the individual level. Recommendation groups were already classified into focus areas by the second digit in the five digit assessment recommendation code (see **Table 4.10**). The recommendations present in each ranking: least cost (**Table 4.1**), greatest savings (**Table 4.2**), shortest payback period (**Table 4.3**), and implementation frequency (**Table 4.4**) were tallied according to the pre-classified focus areas and presented in **Figures 4.1-4.4**, respectively.

Table 4.10: *Assessment recommendation code classifications.*

ARC2	Focus Area
2.1xxx	Combustion Systems
2.2xxx	Thermal Systems
2.3xxx	Electrical Power
2.4xxx	Motor Systems
2.5xxx	Industrial Design
2.6xxx	Operations
2.7xxx	Building & Grounds
2.8xxx	Ancillary Costs

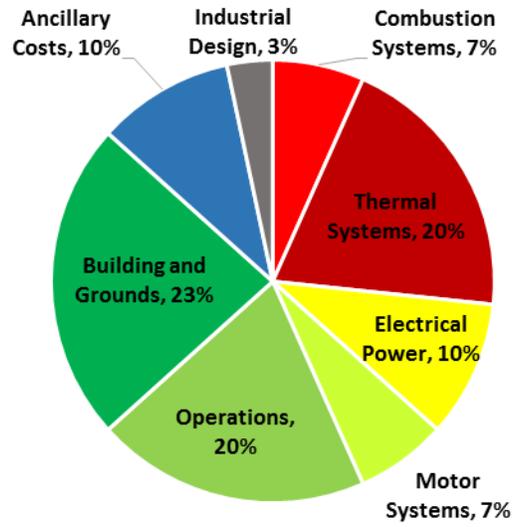


Figure 4.1: Least cost focus area grouping.

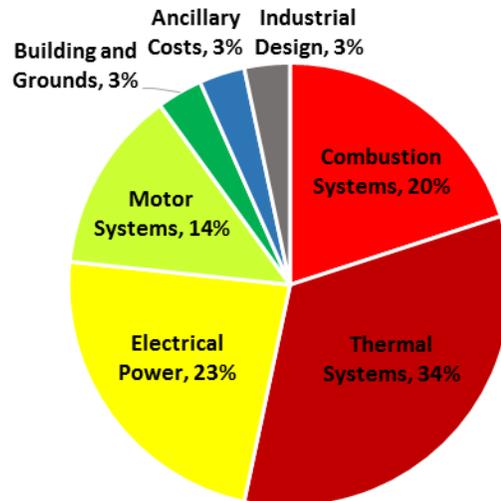


Figure 4.2: Greatest savings focus area grouping.

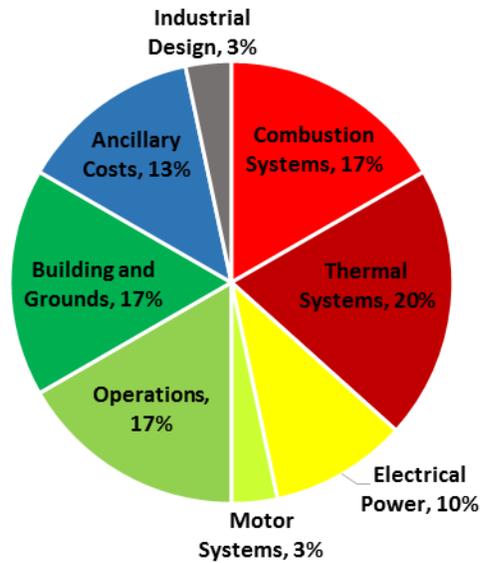


Figure 4.3: Shortest payback focus area grouping.

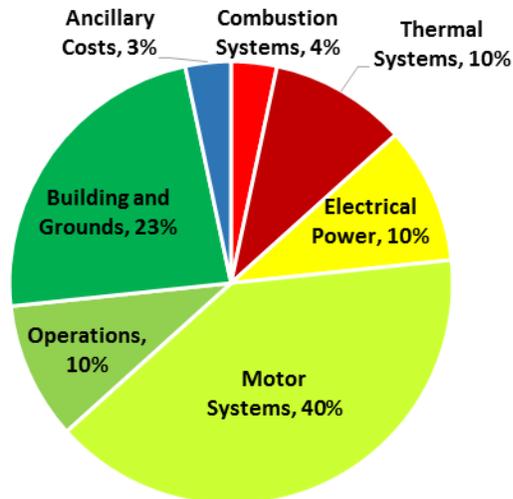


Figure 4.4: Most frequently implemented focus area grouping.

From **Figure 4.1** (least cost grouping) and **Figure 4.3** (shortest payback grouping) we observe a similar distribution of the focus areas, a pattern which is consistent with the results in

Table 4.6. With little exception, the focus areas with the lowest costs have the shortest payback periods. The largest variance between **Figure 4.1** and **4.3** is in combustion systems, which had a difference of 10 percent.

In **Figure 4.2** (greatest savings grouping) combustion and thermal systems recommendations make up 54 percent of the chart while electric power and motor systems recommendations make up 37 percent. This finding is consistent with the work of Kudra (2004), Reeb (1997), Tschernitz (1991), Wengert & Meyer (1992), and Wengert (1980) who consider boiler and kiln operations to be highly energy intensive and one of the least energy efficient processes in wood products manufacturing. The second most energy intensive area is sawing, which is heavily tied to the motor systems driving the saws (Lin et al. 2012; Wengert & Meyer 1992). It makes sense that energy recommendations focused on combustion systems (boiler operations), thermal systems (kiln-drying operations), electrical power, and motor systems (sawing operations) return the greatest savings; these systems consume the greatest portions of energy and in the case of boilers and kilns typically have low efficiencies.

In **Figure 4.4** (most frequently implemented grouping) electrical power and motor systems recommendations make up exactly half of the chart while combustion and thermal systems recommendations make up 14 percent. This finding corroborates the initial observation that wood products manufacturers were not focused on implementing recommendations purely by cost, savings, or payback criteria. If the manufacturers were focused on implementing recommendations by cost, savings, or payback criteria it would be expected that the focus areas in **Figure 4.4** would share a similar distribution to the distributions of focus areas present in **Figures 4.1, 4.2, or 4.3.**

Based on the findings from **Figures 4.1-4.4**, it is hypothesized that wood products manufacturers chose to implement recommendations that would have a direct impact on their variable costs. In other words, these manufacturers implemented recommendations that would make an observable impact on their utility bills. Again, referring to **Figure 4.4** (most frequently implemented grouping), only 14 percent of the recommendations were directed at combustion and thermal systems. According to Bergman and Bowe (2008) more than 90 percent of lumber dried in the U.S. use in-house wood residues from the milling processes as fuel. Unless the manufacturer was in a circumstance where they were purchasing fuel for their boiler or kiln operations or were calculating the opportunity costs of selling their biomass, they most likely did not monitor the costs of fueling their combustion and thermal systems.

If using biomass as fuel, the energy consumption to monetary cost conversion requires thermodynamic mathematical equations; variables of which would require constant monitoring of the fuel moisture content, the species of the biomass fuel, the combustion efficiency of the boiler, heat losses from blow down, venting, loading, leaks, and conduction, the species of wood being dried, the moisture content of the wood being dried, the latent heat required to evaporate water, and the heat capacity required to heat the lumber and building to drying temperature (*Ananias et al. 2012; Anderson & Westerlund 2014; Denig et al 2000; Elustondo & Oliveira 2006; Tschernitz 2001*). Given the complexity of these equations, it is my opinion that the trouble of accurately measuring and maintaining all of these data points for waste residue is likely not worth the hassle for management to bother with. However, in cases where fuel is purchased for the combustion system, any improvements which reduce energy consumption or increase energy efficiency should reduce fuel consumption. The reduced consumption would translate to reduced costs as the fuel would not be purchased as often or it would be purchased in smaller quantities.

The other 86 percent of the recommendations in **Figure 4.4** (most frequently implemented grouping) are recommendations that would impact the cost of electricity for manufacturers. Whether it was through the use of higher efficiency motors, improved maintenance, the use of energy efficient light bulbs and ballasts, or tax incentives on purchased energy, each of the practices making up the 86 percent of the most frequently implemented recommendations could impact the total cost of electricity.

Based on the findings from **Tables 4.1 – 4.8**, it is my opinion that recommendations in the IAC database that fall under the category of “most frequently implemented” have the greatest potential for fitting well into any wood products manufacturer’s energy management program and produce effective results for the overall industry on a day-to-day basis. This opinion is based on the observation of how rarely recommendations in the least cost, greatest savings, and shortest payback rankings were implemented. A low rate of implementation suggests that only a few manufacturers found those recommendations worthwhile. On the other hand, high rates of implementation suggests that those recommendations will apply to a larger demographic of manufacturers.

Secondly, based on the findings from **Figures 4.1 – 4.4** and literature regarding the subject, it is my opinion that recommendations which focus on boiler and kiln operations will save the greatest amount of energy for manufacturers with those operations. Fifty-four percent of the recommendations in the greatest savings focus area grouping are directed toward thermal and combustion systems. It should be noted however that the energy savings from thermal and combustion systems may not be as obvious in terms of monetary savings as electric and motor

systems focused recommendations without calculating fuel consumption and combustion efficiency at the time of this writing.

CHAPTER 5 – DATABASE ANALYSIS (INFERENTIAL STATISTICS)

5.1 Introduction

This chapter focuses on the comparisons of implemented energy recommendations by cost, savings, and payback criteria between wood and non-wood manufacturers and between primary and secondary wood manufacturers; objective 2.

5.2 Results and Discussion

5.2.1 Comparison Results of Wood and Non-wood Products Manufacturers

The energy recommendations which were significantly different at an alpha level of 0.05 based on the Wilcoxon sum-rank tests between wood and non-wood products manufacturers are provided in **Table 5.1**. Screen shots of the significant Wilcoxon sum-rank test results for wood and non-wood manufacturers are provided in **Appendix G**.

Table 5.1: Significantly different recommendations and p-values between wood and non-wood manufacturers.

ARC2	Description	Cost	Saved	Payback
2.2434	Recover heat from air compressor		0.0226	
2.4111	Utilize energy-efficient belts and other improved mechanisms		0.0020	
2.4133	Use most efficient type of electric motors			<.0001
2.4141	Use multiple speed motors or AFD for variable pump, blower and compressor loads		0.0020	
2.4221	Install compressor air intakes in coolest locations	0.0037		
2.4231	Reduce the pressure of compressed air to the minimum required	0.0214		0.0253
2.4232	Eliminate or reduce compressed air used for cooling, agitating liquids, moving product, or drying	0.0458	0.0149	
2.4236	Eliminate leaks in inert gas and compressed air lines/ valves	<.0001		<.0001
2.6232	Install set-back timers	0.0356		0.0133
2.7135	Install occupancy sensors	0.0139		0.0008
2.7142	Utilize higher efficiency lamps and/or ballasts	0.0051	<.0001	
2.8121	Apply for tax-free status for energy purchases	0.0025	<.0001	0.0073

As seen in **Table 5.1**, there are 12 recommendations that received a significant p-value in at least one criteria: cost, savings, or payback period between wood and non-wood products

manufacturers. Only recommendation 2.8121 (Apply for tax-free status for energy purchases) received a significant p-value in each criteria, six recommendations received a significant p-value in at least two of the criteria, and the remaining five recommendations only received a significant p-value in one criteria.

To gain a better understanding of the differences between wood and non-wood manufacturers, the absolute difference in averages of the 12 recommendations present in **Table 5.1** were plotted by each criteria, regardless if one or two of the criteria were not significantly different (see **Figures 5.1-5.3**) The values used to obtain the absolute differences between wood and non-wood manufacturers may be found in **Appendix F**.

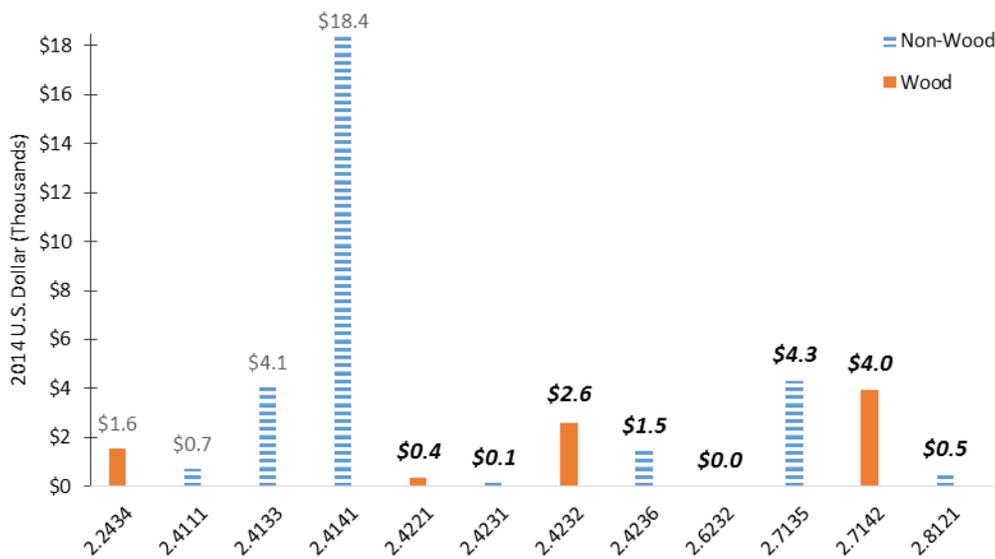


Figure 5.1: Absolute difference in average cost per recommendation between wood and non-wood manufacturers. Note: The bars are color coded to show which manufacturing group had the lower average cost. Data points that are bold and italicized represent significance.

Recommendations 2.4221 (Install compressor air intakes in coolest locations), 2.4232 (Eliminate or reduce compressed air used for cooling, agitating liquids, moving product, or drying), 2.6232 (Install set-back timers), and 2.7142 (Utilize higher efficiency lamps and/or

ballasts) had significantly different costs that favored wood products manufacturers. Recommendations 2.4231 (Reduce the pressure of compressed air to the minimum required), 2.4236 (Eliminate leaks in inert gas and compressed air lines/ valves), 2.7135 (Install occupancy sensors), and 2.8121 (Apply for tax-free status for energy purchases) had significantly different costs that favored non-wood products manufacturers.

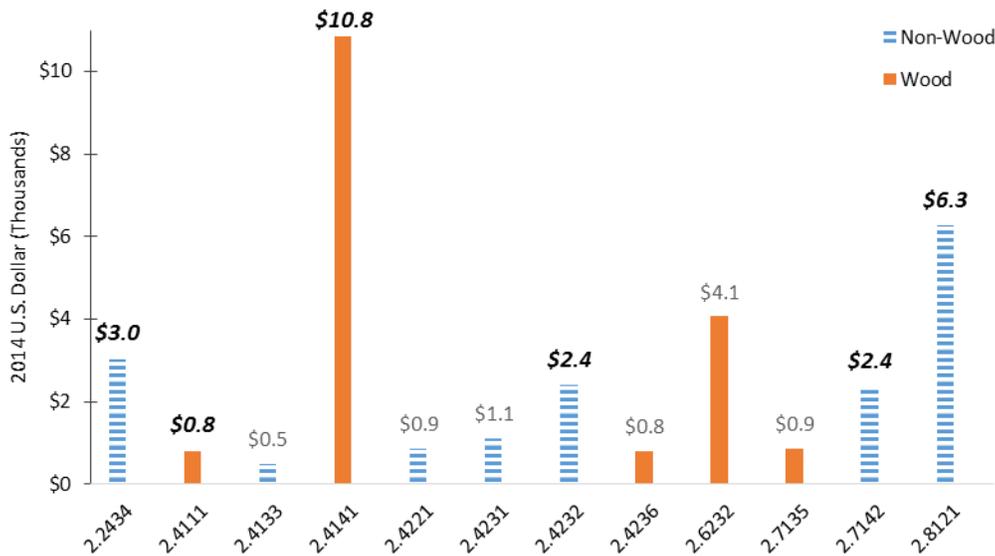


Figure 5.2: Absolute difference in average savings per recommendation between wood and non-wood manufacturers. Note: The bars are color coded to show which manufacturing group had the higher average savings. Data points that are bold and italicized represent significance.

Recommendations 2.4111 (Utilize energy-efficient belts and other improved mechanisms) and 2.4141 (Use multiple speed motors or AFD for variable pump, blower and compressor loads) had significantly different savings favoring wood products manufacturers. Recommendations 2.2434 (Recover heat from air compressor), 2.4232 (Eliminate or reduce compressed air used for cooling, agitating liquids, moving product, or drying), 2.7142 (Utilize higher efficiency lamps and/or ballasts), and 2.8121 (Apply for tax-free status for energy purchases) had significantly different savings favoring non-wood products manufacturers.

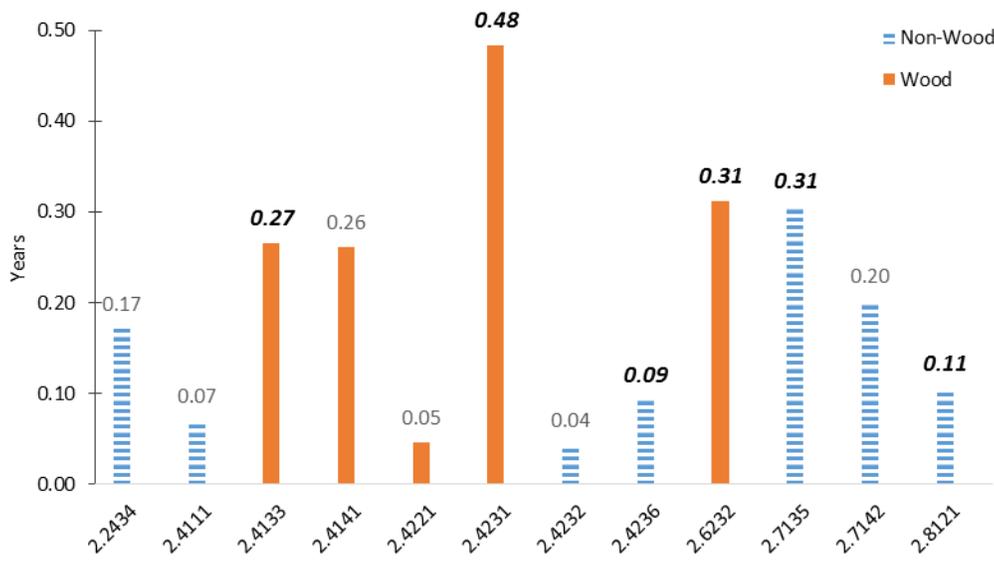


Figure 5.3: Absolute difference in average payback period per recommendation between wood and non-wood manufacturers. Note: The bars are color coded to show which manufacturing group had the shorter average payback period. Data points that are bold and italicized represent significance.

Recommendations 2.4133 (Use most efficient type of electric motors), 2.4231 (Reduce the pressure of compressed air to the minimum required), and 2.6232 (Install set-back timers) had significantly different payback periods favoring wood products manufacturers. Recommendations 2.4236 (Eliminate leaks in inert gas and compressed air lines/ valves), 2.7135 (Install occupancy sensors), and 2.8121 (Apply for tax-free status for energy purchases) had significantly different payback periods favoring non-wood products manufacturers.

Despite the findings in **Table 5.1**, in which at least one criteria of the 12 recommendations was found to be statistically different between wood and non-wood manufacturers there is little practical difference (a difference that could have meaningful effects in business operations) between the manufacturing groups. Regardless of initial costs or expected savings, **Figure 5.3**

shows that the largest difference in expected payback period is slightly less than half a year and the average difference is 0.20 years, or 2.4 months.

According to the U.S. DOE (2015), manufacturers frequently require payback periods of one to three years. In a survey conducted by Espinoza et al. (2015), when wood product manufacturers were asked how long an acceptable payback period would make cogeneration an attractive investment, 13.3 percent of the respondents said 5 years or less, 15.6 percent said 20 years or less, and 66.7 percent said they didn't know enough to answer the question. Based on these sources, it seems unlikely that a time period of a few months would have much of an impact on manufacturer's decisions.

5.2.2 Comparison Results of Primary and Secondary Wood Products Manufacturers

The energy recommendations which were significantly different at an alpha level of 0.05 based on the Wilcoxon sum-rank tests between primary and secondary wood products manufacturers are provided in **Table 5.2**. Screen shots of the significant Wilcoxon sum-rank test results for primary and secondary wood manufacturers are provided in **Appendix H**.

Table 5.2: Significantly different recommendations and p-values between primary and secondary manufacturers.

ARC2	Description	Cost	Saved	Payback
2.1233	Analyze flue gas for proper air/fuel ratio		0.0136	
2.2131	Insulate steam / hot water lines			0.0201
2.3131	Reschedule plant operations or reduce load to avoid peaks		0.0479	
2.3212	Optimize plant power factor	0.0308	0.0146	
2.4111	Utilize energy-efficient belts and other improved mechanisms	0.0227	<.0001	
2.4133	Use most efficient type of electric motors	<.0001	0.0003	
2.4151	Develop a repair/replace policy			0.0032
2.4221	Install compressor air intakes in coolest locations		0.0173	0.0239
2.4236	Eliminate leaks in inert gas and compressed air lines/ valves	<.0001	<.0001	0.0463
2.4314	Use synthetic lubricant	0.0267		
2.6212	Turn off equipment during breaks, reduce operating time	0.0075		0.0044
2.6218	Turn off equipment when not in use		0.0253	
2.6232	Install set-back timers	0.0397		0.0250

2.7135	Install occupancy sensors	0.0455	0.0203	
2.8121	Apply for tax-free status for energy purchases	0.0009	0.0014	0.0009

From **Table 5.2** we see there were 15 recommendations that received a significant p-value in at least one criteria: cost, savings, or payback period between primary and secondary wood manufacturers. Recommendations 2.4236 (Eliminate leaks in inert gas and compressed air lines/valves) and 2.8121 (Apply for tax-free status for energy purchases) received a significant p-value in each criteria, seven recommendations received a significant p-value in at least two of the criteria, and the remaining six recommendations only received a significant p-value in one criteria.

To get a better understanding of the differences between primary and secondary wood manufacturers, the absolute difference in averages of the 15 recommendations present in **Table 5.2** were plotted by each criteria, regardless if one or two of the criteria were not significantly different (see **Figures 5.4-5.6**). The values used to obtain the absolute differences between the primary and secondary manufacturers may be found in **Appendix F**.

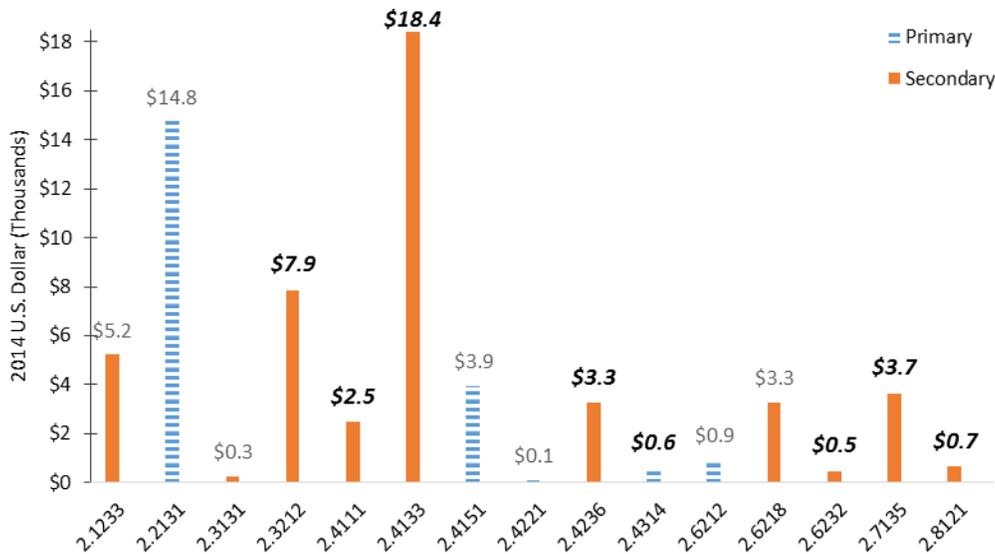


Figure 5.4: Absolute difference in average cost per recommendation between primary and secondary wood manufacturers. Note: The bars are color coded to show which manufacturing

group had the lower average cost. Data points that are bold and italicized represent significance.

Only recommendation 2.4314 (Use synthetic lubricant) had a significantly different cost favoring primary manufactures. Recommendations 2.3212 (Optimize plant power factor), 2.4111 (Utilize energy-efficient belts and other improved mechanisms), 2.4133 (Use most efficient type of electric motors), 2.4236 (Eliminate leaks in inert gas and compressed air lines/ valves), 2.6232 (Install set-back timers), 2.7135 (Install occupancy sensors), and 2.8121 (Apply for tax-free status for energy purchases) had significantly different costs favoring secondary manufacturers.

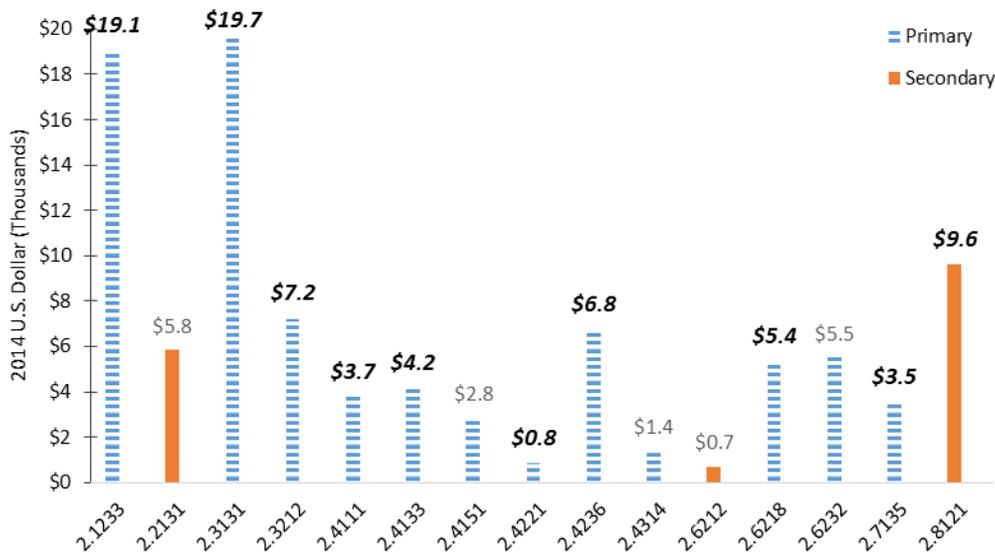


Figure 5.5: Absolute difference in average savings per recommendation between primary and secondary wood manufacturers. Note: The bars are color coded to show which manufacturing group had the higher average savings. Data points that are bold and italicized represent significance.

Recommendations 2.1233 (Analyze flue gas for proper air/fuel ratio), 2.3131 (Reschedule plant operations or reduce load to avoid peaks), 2.3212 (Optimize plant power factor), 2.4111 (Utilize energy-efficient belts and other improved mechanisms), 2.4133 (Use most efficient type

of electric motors), 2.4221 (Install compressor air intakes in coolest locations), 2.4236 (Eliminate leaks in inert gas and compressed air lines/ valves), 2.6218 (Turn off equipment when not in use), and 2.7135 (Install occupancy sensors) had significantly different savings favoring primary manufacturers. Only recommendation 2.8121 (Apply for tax-free status for energy purchases) had a significantly different saving favoring secondary manufacturers.

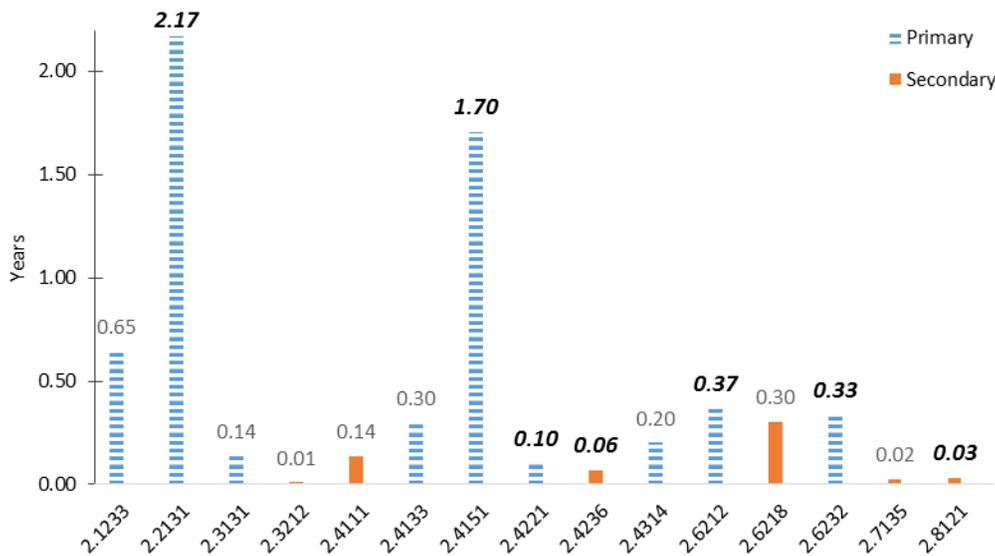


Figure 5.6: Absolute difference in average payback period per recommendation between primary and secondary wood manufacturers. Note: The bars are color coded to show which manufacturing group had the shorter average payback period. Data points that are bold and italicized represent significance.

Recommendations 2.2131 (Insulate steam / hot water lines), 2.4151 (Develop a repair/replace policy), 2.4221 (Install compressor air intakes in coolest locations), 2.6212 (Turn off equipment during breaks, reduce operating time), and 2.6232 (Install set-back timers) had significantly different payback periods favoring primary manufacturers. Recommendations 2.4236 (Eliminate leaks in inert gas and compressed air lines/ valves) and 2.8121 (Apply for tax-free status for energy purchases) had significantly different payback periods favoring secondary manufacturers.

Based on the findings in **Figures 5.4 – 5.6**, it is my opinion that while at least one criteria for each of these 15 recommendations was found to be statistically different between primary and secondary wood manufacturers, only two recommendations appear to have practical differences (a difference that could have meaningful effects in business operations) between the manufacturing groups. From **Figure 5.6**, we see that recommendations 2.2131 (Insulate steam / hot water lines) and 2.4151 (Develop a repair/replace policy) have large significantly different payback periods favoring primary wood products manufacturers. Recommendation 2.2131 cost \$14,800 less on average for primary manufacturers, saved an average \$5,800 more for secondary manufacturers, and had an average 2.71 years shorter payback period for primary manufacturers. Recommendation 2.4151 cost \$3,900 less on average for primary manufacturers, saved an average \$2,800 more for primary manufacturers, and had an average 1.70 years shorter payback period for primary manufacturers. While these recommendations are a part of the 30 most frequently implemented rankings and are important to wood products manufacturers it appears that both recommendations 2.2131 (Insulate steam/hot water lines) and 2.4151 (Develop a repair/replace policy) have significantly shorter payback periods by magnitudes of years for primary wood products manufacturers.

The differences between primary and secondary wood manufacturers are larger than that of wood and non-wood manufacturers. From **Tables 5.1 and 5.2**, we see wood vs. non-wood manufacturers have 12 total recommendations that exhibited a significant difference in at least one criteria while primary vs. secondary wood manufacturers had 15. Also, the average difference in cost, savings, and payback for wood vs. non-wood manufacturers were \$3,100, \$2,800, and 0.20 years, respectively; while the average difference in cost, savings, and payback for primary vs.

secondary manufacturers were \$4,400, \$6,400, and 0.43 years, respectively. This suggests that there are larger differences between primary and secondary manufacturers than those of wood and non-wood manufacturers. Based on these findings, it is my opinion that wood manufactures and non-wood manufacturers encompass such a large sample that more subtle differences won't be exposed. Comparing manufacturers by similar key factors such as industry maturity, reliance on agricultural materials, or small profit margins may reveal more telling results in any future research.

5.2.3 Exploring Differences

For energy recommendations that were significantly different between the manufacturing groups; a backward regression analysis was going to be performed to discover which variables influenced the response variables. The results of this secondary analysis would be used to explain what contributed to the detected difference.

Several problems arose while attempting to apply this analysis. The first issue was missing data. There were 25,367 entries for the significantly different recommendations between wood and non-wood products manufacturers. Among those 25,367 entries 11,535 data points for USAGE_DEMD, 5,926 data points for PLANT_AREA, and 4,140 data points for USAGE_NAT were missing as seen in **Table 5.3**. There were 1,519 entries for the significantly different recommendations between primary and secondary wood products manufacturers. Among those 1,519 entries 709 data points for USAGE_DEMD, 674 data points for USAGE_NAT, and 476 data points for PLANT_AREA were missing as seen in **Table 5.4**.

Table 5.3: *Number of missing data points by variable for wood and non-wood manufacturers (25,367 total records).*

Variable	Missing Data Points
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USAGE_DEMD	11,535
PLANT_AREA	5,926
USAGE_NAT	4,140
SALES	129
PRODHOURS	109
USAGE_ELEC	33
EMPLOYEES	24

Table 5.4: Number of missing data points by variable for primary and secondary manufacturers (1,519 total records).

Variable	Missing Data Points
USAGE_DEMD	709
USAGE_NAT	674
PLANT_AREA	476
PRODHOURS	20
SALES	6
EMPLOYEES	3
USAGE_ELEC	3

Due to the large amount of missing data for variables PLANT_AREA, USAGE_DEMD, and USAGE_NAT, it was decided that they would not be used in the backward regression because their presence would eliminate a large portion of otherwise viable data. This left explanatory variables EMPLOYEES, PRODHOURS, SALES, USAGE_ELEC available for analysis.

The linear relationship of the four remaining explanatory variables and the response variables were measured for each manufacturing group as linearity between the explanatory and response variables is a requirement of regression analysis. A correlation coefficient of either 1 or -1 represents a perfect linear relationship while a correlation coefficient of 0 represents no linear relationship between two variables. The results of the correlations for each manufacturing group are presented below, the area of interest is enclosed with a red box (see **Figures 5.7-5.10**).

Correlations							
	Cost	Saved	Payback	SALES	EMPLOYEES	PRODHOURS	USAGE_ELEC
Cost	1.0000	0.6023	0.0375	0.0688	0.1051	0.0672	0.1210
Saved	0.6023	1.0000	-0.0066	0.1312	0.1819	0.1257	0.2299
Payback	0.0375	-0.0066	1.0000	0.0008	0.0063	-0.0096	0.0001
SALES	0.0688	0.1312	0.0008	1.0000	0.2660	0.0672	0.2830
EMPLOYEES	0.1051	0.1819	0.0063	0.2660	1.0000	0.1228	0.2279
PRODHOURS	0.0672	0.1257	-0.0096	0.0672	0.1228	1.0000	0.1710
USAGE_ELEC	0.1210	0.2299	0.0001	0.2830	0.2279	0.1710	1.0000

There are 263 missing values. The correlations are estimated by Pairwise method.

Figure 5.7: Correlation matrix of variables specific to non-wood manufacturers.

Correlations							
	Cost	Saved	Payback	SALES	EMPLOYEES	PRODHOURS	USAGE_ELEC
Cost	1.0000	0.5477	0.0913	0.1390	0.0410	0.1069	0.1326
Saved	0.5477	1.0000	-0.0226	0.2388	0.1376	0.2111	0.3250
Payback	0.0913	-0.0226	1.0000	-0.0176	-0.0365	-0.0204	-0.0236
SALES	0.1390	0.2388	-0.0176	1.0000	0.4656	0.2412	0.3317
EMPLOYEES	0.0410	0.1376	-0.0365	0.4656	1.0000	0.1691	0.2487
PRODHOURS	0.1069	0.2111	-0.0204	0.2412	0.1691	1.0000	0.4620
USAGE_ELEC	0.1326	0.3250	-0.0236	0.3317	0.2487	0.4620	1.0000

There are 29 missing values. The correlations are estimated by REML method.

Figure 5.8: Correlation matrix of variables specific to wood manufacturers.

Correlations							
	Cost	Saved	Payback	SALES	EMPLOYEES	PRODHOURS	USAGE_ELEC
Cost	1.0000	0.4245	0.2217	0.1097	0.0544	0.1076	0.0759
Saved	0.4245	1.0000	-0.0419	0.1989	0.2023	0.1752	0.2221
Payback	0.2217	-0.0419	1.0000	-0.0229	-0.0610	-0.0159	-0.0356
SALES	0.1097	0.1989	-0.0229	1.0000	0.4486	0.2618	0.3284
EMPLOYEES	0.0544	0.2023	-0.0610	0.4486	1.0000	0.3377	0.4139
PRODHOURS	0.1076	0.1752	-0.0159	0.2618	0.3377	1.0000	0.4291
USAGE_ELEC	0.0759	0.2221	-0.0356	0.3284	0.4139	0.4291	1.0000

There are 11 missing values. The correlations are estimated by REML method.

Figure 5.9: Correlation matrix of variables specific to primary manufacturers.

Correlations							
	Cost	Saved	Payback	SALES	EMPLOYEES	PRODHOURS	USAGE_ELEC
Cost	1.0000	0.4458	0.2768	0.0490	0.0646	0.1106	0.0975
Saved	0.4458	1.0000	-0.0771	0.1524	0.1455	0.1094	0.1645
Payback	0.2768	-0.0771	1.0000	-0.0356	-0.0376	0.0370	-0.0297
SALES	0.0490	0.1524	-0.0356	1.0000	0.7413	0.2157	0.4584
EMPLOYEES	0.0646	0.1455	-0.0376	0.7413	1.0000	0.2141	0.5641
PRODHOURS	0.1106	0.1094	0.0370	0.2157	0.2141	1.0000	0.4344
USAGE_ELEC	0.0975	0.1645	-0.0297	0.4584	0.5641	0.4344	1.0000

There are 19 missing values. The correlations are estimated by REML method.

Figure 5.10: Correlation matrix of variables specific to secondary manufacturers.

The results of the multivariate correlations revealed that the proposed explanatory variables and response variables had weak linear relationships, R-values less than 0.3. As there was weak linearity between the variables, regression would not produce viable results. Therefore, it was determined that further analysis of the data using backward regression was not possible. Because this secondary analysis was not specifically part of the expected deliverables, no further investigations were made. If this analysis were to be pursued further in the future, I suggest that perhaps a non-linear type of regression may be more useful for this set of data. However, after having worked intimately with the IAC database, I believe that such fine analysis of these variables would not greatly increase our understanding of why these comparisons results are as they are. Missing data is the main reason for this belief, followed by potentially confounding variables.

CHAPTER 6 – LEAN-ENERGY RECOMMENDATIONS

6.1 Introduction

This chapter focuses on the identity of energy recommendations from the IAC database, implemented by wood products manufacturers, which incorporate lean management practices or principles; objective 3. This was accomplished by matching lean tools to energy recommendations and determining the effect of the recommendation on energy performance (see section 3.7).

6.2 Results and Discussion

6.2.1 *Specifically Lean*

Using the criteria outlined in section 3.7, only two recommendations met the “specifically lean” criteria and are presented below beginning with the energy recommendation code and its definition in CAPS, followed by the corresponding lean tool and its definition. Both would be associated with TPM according to the lean house model presented in section 3.7.

2.4156 – ESTABLISH A PREVENTATIVE MAINTENANCE PROGRAM

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

2.4157 – ESTABLISH A PREDICTIVE MAINTENANCE PROGRAM

Predictive Maintenance – A maintenance strategy in which machines are analyzed with special equipment that can predict machine failure based on vibration, lubrication, temperature, and other analyses, with an emphasis on planned maintenance.

Neither of these specifically lean energy recommendations were present in the top 30 rankings of wood products manufacturers based on least cost, greatest savings, shortest payback period, or most frequently implemented from chapter 4. These results obviously conclude that the specifically lean energy recommendations were not the cheapest to implement, did not save the largest amounts of money, were not the fastest in terms of payback period, and were not

implemented often. The data of these two recommendations for wood manufactures is provided in **Table 6.1**.

Table 6.1: Specifically lean energy recommendations

ARC2	Description	Imp. Freq.	Avg. Cost	Avg. Saved Per Year	Avg. Payback
2.4156	Establish a preventative maintenance program	2	\$7,333.71	\$33,104.68	0.32
2.4157	Establish a predictive maintenance program	10	\$2,482.55	\$6,718.87	0.41

It is important to understand the results in **Table 6.1** do not include the productivity gains that could be attributed to their implementation, such as reduced downtime, speed, and quality losses. These data are reflections of saving through energy only. Any productivity gains could be attributed to greater savings which would also decrease the payback period of these recommendations. Furthermore, when comparing these recommendations to the 30 most frequently implemented recommendations by wood manufactures in **Table 4.4**, we see that while they are infrequently implemented, their average costs aren't the highest, their average savings aren't the lowest, and their average payback periods are very reasonable. If productivity gains were calculated and added to the energy-related gains, these recommendations may demonstrate the superior performance described in Quesada & Bond (2013).

6.2.2 Descriptively Lean

Four recommendations met the descriptively lean criteria and are presented below beginning with the energy recommendation code and its definition in CAPS, followed by the corresponding lean tool and its definition. Recommendations 2.1231, 2.3135, and 2.6124 would be associated with TPM and 2.5121 associated with plant layout according the lean house model presented in section 3.7.

2.1231 – ESTABLISH BURNER MAINTENANCE SCHEDULE FOR BOILERS

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

2.3135 – SCHEDULE ROUTINE MAINTENANCE DURING NON-OPERATING PERIODS

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

2.5121 – REDESIGN FLOW TO MINIMIZE MASS TRANSFER LENGTH

Flow Cells – Manufacturing or assembling in a layout in which all (or most) of the parts and machines necessary to complete a part or assembly are in close proximity of one another.

2.6124 – ESTABLISH EQUIPMENT MAINTENANCE SCHEDULE

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

Two of the descriptively lean recommendations were present in both the least cost and shortest payback rankings for wood products manufacturers from chapter 4 (see **Table 6.2**).

Table 6.2: Present in the least cost and shortest payback rankings.

ARC2	Description	Imp. Freq.	Avg. Cost	Avg. Saved Per Year	Avg. Payback
2.3135	Schedule routine maintenance during non-operating periods	1	\$0.00	\$874.97	0.00
2.6124	Establish equipment maintenance schedule	1	\$97.47	\$963.04	0.10

We see from **Table 6.2** that recommendations 2.3135 and 2.6124 have a very low cost, which lends them a very low payback period. The low payback period matches the work of Quesada and Bond (2013), however the savings of these recommendations are low and recommendations 2.1231 and 2.5121 are not present in any of the top 30 rankings given in chapter 4. Again, it is important to point out that these data are representations of savings through energy alone and if productivity gains were incorporated the savings and payback period would increase and decrease, respectively. However, because these recommendations were only implemented once each it is difficult to comment on whether they would have any superior affect such as greater

savings or relative shorter payback periods due to their lean manufacturing and energy management nature.

6.2.3 Arguably Lean

Eighteen recommendations met the arguably lean criteria and are presented below beginning with the energy recommendation code and its definition in CAPS, followed by the corresponding lean tool and its definition. Some energy recommendations may have more than one lean tool associated with it. The argument of how the energy recommendation and lean tool are associated are added for each recommendation and tool pair. All arguably lean recommendations but 2.5194, 2.5195, and 2.6231 would be associated with TPM according to the lean house model presented in section 3.7. Recommendations 2.1232, 2.6125, and 2.6127 would be associated with 5s, recommendations 2.5194 and 2.5195 would be associated with plant layout, while recommendations 2.1233 and 2.6231 would be associated with quality at source according to the lean house model presented in section 3.7.

2.1131 – REPAIR FAULTY INSULATION IN FURNACES, BOILERS, ETC

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

If repairs of faulty insulation in furnaces, boilers, etc. are checked and repaired on a regular schedule it would fit under preventative maintenance.

2.1132 – REPAIR FAULTY LOUVERS AND DAMPERS

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

If repairs of faulty louvers and dampers are checked and repaired on a regular schedule it would fit under preventative maintenance.

2.1232 – KEEP BOILER TUBES CLEAN

5s – Five Japanese words for creating and maintaining a clean, organized work environment: Seiri (sifting), Seiton (Sorting), Seiso (Sweeping), Seiketsu (Standardize), Shitsuke (Sustain).

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

If the cleaning of boiler tubes is part of a methodical cleanliness and organizational strategy it would fit under 5s. If the cleaning of boiler tubes is conducted on a regular schedule it would fit under preventative maintenance.

2.1233 – ANALYZE FLUE GAS FOR PROPER AIR/FUEL RATIO

Statistical Process Control – Use of control charts to study processes and determine when the process is out of control.

Total Productive Maintenance – A maintenance strategy, which incorporates the operators in daily maintenance activities, such as, checking for vibrations, oil and lubrication, etc.

If the analysis data of flue gas for proper air/fuel ratio is collected and used to control the process it would fit under statistical process control. If the analysis of data of flue gas for proper air/fuel ration was collected daily to determine if the ratio was optimal it would fit under total productive maintenance.

2.2113 – REPAIR OR REPLACE STEAM TRAPS

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

If repairs or replacements of steam traps are checked and repaired or replaced on a regular schedule it would fit under preventative maintenance.

2.2122 – INSTALL / REPAIR INSULATION ON CONDENSATE LINES

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

If repairs of insulation on condensate lines are checked and repaired on a regular schedule it would fit under preventative maintenance.

2.2132 – REPAIR FAULTY INSULATION ON STEAM LINES

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

If repairs of faulty insulation on steam lines are checked and repaired on a regular schedule it would fit under preventative maintenance.

2.2133 – REPAIR LEAKS IN LINES AND VALVES

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

If repairs of leaks in lines and valves are checked and repaired on a regular schedule it would fit under preventative maintenance.

2.2135 – REPAIR AND ELIMINATE STEAM LEAKS

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

If repairs and elimination of steam leaks are checked and repaired on a regular schedule it would fit under preventative maintenance.

2.4151 – DEVELOP A REPAIR/REPLACE POLICY

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

If a repair/replace policy is developed to include regularly scheduled inspections and repairs it would fit under preventative maintenance.

2.4236 – ELIMINATE LEAKS IN INERT GAS AND COMPRESSED AIR LINES/ VALVES

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

If leak eliminations in inert gas and compressed air lines/valves are checked and repaired on a regular schedule it would fit under preventative maintenance.

2.4312 – IMPROVE LUBRICATION PRACTICES

Total Productive Maintenance – A maintenance strategy, which incorporates the operators in daily maintenance activities, such as, checking for vibrations, oil and lubrication, etc.

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

If lubrication practices are performed daily it would fit under total productive maintenance.
If lubrication practices are performed on a regular schedule it would fit under preventative maintenance.

2.4313 – PROVIDE PROPER MAINTENANCE OF MOTOR DRIVEN EQUIPMENT

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

Total Productive Maintenance – A maintenance strategy, which incorporates the operators in daily maintenance activities, such as, checking for vibrations, oil and lubrication, etc.

If proper maintenance of motor driven equipment is conducted on a regular schedule it would fit under preventative maintenance. If proper maintenance of motor driven equipment is conducted daily it would fit under total productive maintenance.

2.5194 – REDESIGN PROCESS

Flow Cells – Manufacturing or assembling in a layout in which all (or most) of the parts and machines necessary to complete a part or assembly are in close proximity of one another.

If a redesigned process incorporates flow by having machines properly ordered in close proximity it would fit under flow cells.

2.5195 – CHANGE PRODUCT DESIGN TO REDUCE ENERGY REQUIREMENTS

Flow Cells – Manufacturing or assembling in a layout in which all (or most) of the parts and machines necessary to complete a part or assembly are in close proximity of one another.

If a change of product design which reduces energy requirements incorporates flow by having machines properly ordered in close proximity it would fit under flow cells.

2.6125 – KEEP EQUIPMENT CLEAN

5s – Five Japanese words for creating and maintaining a clean, organized work environment: Seiri (sifting), Seiton (Sorting), Seiso (Sweeping), Seiketsu (Standardize), Shitsuke (Sustain).

Total Productive Maintenance – A maintenance strategy, which incorporates the operators in daily maintenance activities, such as, checking for vibrations, oil and lubrication, etc.

If the cleaning of equipment is part of a methodical cleanliness and organizational strategy it would fit under 5s. If the cleaning of equipment is conducted daily it would fit under total productive maintenance.

2.6127 – MAINTAIN AIR FILTERS BY CLEANING OR REPLACEMENT

5s – Five Japanese words for creating and maintaining a clean, organized work environment: Seiri (sifting), Seiton (Sorting), Seiso (Sweeping), Seiketsu (Standardize), Shitsuke (Sustain).

Preventive Maintenance – A maintenance strategy in which machines are checked or parts are replaced at specified time increments or machine (part) usage.

If the maintenance and cleaning of air filters is part of a methodical cleanliness and organizational strategy it would fit under 5s. If the maintenance and cleaning of air filters is conducted on a regular schedule it would fit under preventative maintenance.

2.6231 – UTILIZE CONTROLS TO OPERATE EQUIPMENT ONLY WHEN NEEDED

Autonomation – Designing a machine to stop automatically when it detects an error in the production process.

If the operation of equipment while it is not needed is considered an error then automatic controls to stop the equipment while it is not needed would fit under autonomation.

Arguably lean recommendation(s) which were present in rankings from chapter 4 were identified and compiled into **Tables 6.3-6.7** according to the rankings they were present in.

Table 6.3: Present in the least cost and shortest payback rankings from chapter 4.

ARC2	Description	Imp. Freq.	Avg. Cost	Avg. Saved	Avg. Payback
2.3135	Schedule routine maintenance during non-operating periods	1	\$0.00	\$874.97	0.00
2.4313	Provide proper maintenance / of motor driven equipment	1	\$0.00	\$2,818.64	0.00
2.5194	Redesign process	1	\$0.00	\$11,572.09	0.00
2.6124	Establish equipment maintenance schedule	1	\$97.47	\$963.04	0.10

Table 6.4: Present in the greatest savings ranking from chapter 4.

ARC2	Description	Imp. Freq.	Avg. Cost	Avg. Saved	Avg. Payback
2.1232	Keep boiler tubes clean	9	\$15,657.11	\$55,504.58	0.46
2.2135	Repair and eliminate steam leaks	13	\$5,617.78	\$73,847.37	1.89
2.5195	Change product design to reduce energy requirements	1	\$211,357.21	\$192,243.67	1.10

Table 6.5: Present in the most frequently implemented ranking from chapter 4.

ARC2	Description	Imp. Freq.	Avg. Cost	Avg. Saved	Avg. Payback
2.1233	Analyze flue gas for proper air/fuel ratio	55	\$5,415.09	\$18,178.42	0.75
2.4151	Develop a repair/replace policy	26	\$4,502.08	\$4,995.05	1.40
2.4236	Eliminate leaks in inert gas and compressed air lines/ valves	488	\$2,975.22	\$7,911.86	0.46

Table 6.6: Present in the least cost and most frequently implemented rankings from chapter 4.

ARC2	Description	Imp. Freq.	Avg. Cost	Avg. Saved	Avg. Payback
2.4312	Improve lubrication practices	19	\$325.37	\$3,330.56	0.33

Table 6.7: Present in the shortest payback ranking from chapter 4.

ARC2	Description	Imp. Freq.	Avg. Cost	Avg. Saved	Avg. Payback
2.1132	Repair faulty louvers and dampers	1	\$548.91	\$2,870.79	0.19

As seen in **Tables 6.3-6.7** above, there are 12 recommendations classified as arguably lean that appeared in at least one ranking from chapter 4. The average costs of these recommendations range from \$0.00 to \$211,357.21, the average savings range from \$874.97 to \$192,243.67, and the average payback period ranges from 0.00 years to 1.89 years. Compared to the least cost ranking range of \$0.00 to 464.93, the greatest savings ranking range of \$1,223,439.17 to 33,859.93, and the shortest payback ranking range of 0.00 years to 0.19 years, these lean-based energy recommendations are not inherently superior. Based on the data collected for these recommendations there is no clear evidence to suggest these arguably lean recommendations are any different from simple energy recommendations in terms of cost, savings, or payback period. However, it is important to consider the two major limitations of these arguably lean energy recommendations. First, unlike the specifically or descriptively lean energy recommendations, these arguably lean energy recommendations would need to meet specific criteria to be considered lean. Without knowing the specific practices for each manufacturer no viable conclusion could be made about whether these recommendations were implemented only once or were in fact practiced continuously as they should be according to lean principles. Second, just like the specifically and descriptively lean energy recommendations, these arguably lean recommendations represent the savings of energy. Productivity gains would need to be incorporated to truly determine if they result in larger savings and shorter payback periods relative to simple energy recommendations.

6.2.4 Waste Elimination and Non-lean Recommendations

Of the 192 energy recommendations given to wood products manufactures, only 24 recommendations were chosen to be classified as lean by the methods of matching them to Kirby and Green's (2003) lean tools as described in section 3.7. It is important to restate that the primary goal of lean is maximizing value while minimizing waste (*Lean Enterprise Institute 2016*). From

this context alone, it could be argued that any practice that reduces the energy consumption of a process while still providing the same service has reduced non-value added energy consumption and must therefore be lean. Presented in **Table 6.8** are 22 energy recommendations, of the 192 implemented by the wood products manufacturers, which could not be lean as they do not result in energy conservation or efficiency, meaning they do not minimize non-value added energy waste; instead, they are methods for lowering energy costs.

Table 6.8: *Non-lean energy recommendations.*

ARC2	Description
2.1311	Replace electrically-operated equipment with fossil fuel equipment
2.1321	Replace fossil fuel equipment with electrical equipment
2.1331	Burn a less expensive grade of fuel
2.1335	Replace gasoline with diesel, LPG, or natural gas
2.1392	Replace purchased steam with other energy source
2.2628	Utilize a less expensive cooling method
2.3131	Reschedule plant operations or reduce load to avoid peaks
2.3132	Recharge batteries on during off-peak demand periods
2.3133	Consider three or four days around-the-clock operation rather than one or two shifts per day
2.3134	Shift from daytime to nighttime operation
2.3137	Use power during off-peak periods
2.3191	Use demand controller or load shedder
2.3192	Use fossil fuel powered generator during peak demand periods
2.3211	Use power factor controllers
2.3212	Optimize plant power factor
2.4112	Install soft-start to eliminate nuisance trips
2.8111	Check for accuracy of utility meters
2.8112	Combine utility meters
2.8113	Purchase gas directly from a contract gas supplier
2.8114	Change rate schedules or other changes in utility service
2.8121	Apply for tax-free status for energy purchases
2.8123	Pay utility bills on time

Based on the work presented in this section, the 24 energy recommendations identified as either specifically, descriptively, or arguably lean using the lean tools provided by Kirby and Green (2003) all have the potential to increase productivity while improving energy performance. Also of note is how 20 of the 24 recommendations could fall under TPM according to the lean house model presented in section 3.7. This suggests that proper maintenance practices, according to lean

principles, with energy consuming equipment are most likely to reduce energy consumption while increasing productivity. However, the IAC database alone does not contain enough information to determine whether those 24 lean-energy recommendations have superior savings or payback periods because productivity gains are not included in the savings or payback periods. For this reason, I suggest that future researchers work with manufacturers and measure the effect of the 24 lean-energy recommendations to definitively determine any strengths resultant of their increased productivity and energy performance as noted in Quesada and Bond (2013). Considering lean's core principle of maximizing value and minimizing waste, 170 recommendations of the 192 implemented by wood products manufacturers will contribute to minimizing non-value added energy waste (*Lean Enterprise Institute 2016*). Only the 22 recommendations identified in **Table 6.8** will not reduce energy wastes.

CHAPTER 7 – COMPARATIVE CASE STUDY OF MANUFACTURERS

7.1 Introduction

This chapter focuses on the investigation of the energy consumption, energy management practices, and perspectives of wood product manufacturers regarding energy management based on a comparative case study; objective 4.

7.2 Results and Discussion

7.2.1 General Information

Questions 1-9 (**Appendix E**) were asked with the intent of drawing inferences from the respondents' information to the variables that influenced the cost, savings, and payback period of the significantly different recommendations as discussed in section 5. Since the analysis was not able to determine what these variables were, no inferences could be made. Demographic information for the respondents are presented in **Table 7.1** and the results of questions 2-9 are presented in **Table 7.2** below.

Table 7.1: Demographic information.

Manufacturer's Study Code	Interviewee's Position	Primary Business	Classification
A	Director of Mfg. Technology	Wood Household Furniture	Secondary
B	President	Sawmills and Planing Mills (no kiln)	Primary
C	Manager	Other (Dry-Kiln Facility)	Secondary
D	Manager	Other (Dry-kiln Facility)	Secondary
E	Manager	Sawmills and Planing Mills (no kiln)	Primary

Table 7.2: General respondent information.

Mfg.	Area	Employees	Hours	Sales	Purchased Energy	Electric Cons.	Peak Demand	Nat. gas Cons.
A	-	500 +	-	-	Electric & Nat. gas	\$1.8M	2/3 of bill	?
B	46,000 sf	40	2,800	\$9M	Electric	\$144,000	?	n/a
C	40,000 sf	32	2,040	\$25M	Electric & Biomass	\$216,000	?	n/a
D	50,000 sf	22	2,000	\$15M	Electric & Biomass	\$160,000	?	n/a
E	30,000 sf	55	2,000	\$16M	Electric	\$198,000	?	n/a

In addition to electricity, which was purchased by each respondent, manufacturers C and D purchased biomass as fuel for their boiler operations and manufacturer A purchased natural gas but was unaware of how much was consumed. When asked about their peak demand consumption only manufacturer A gave an estimation which they presumed was about 2/3rds of their utility bill.

7.2.2 Consumption Monitoring Practices

Table 7.3: Energy consumption monitoring by respondents.

Mfg.	Level of Electric Metering	Electric Tracking Method	Electric Review Frequency	Level of Nat. gas Metering	Nat. gas Tracking Method	Nat. gas Review Frequency
A	Whole Site	Utility Bills	Annually	?	?	?
B	Building	Utility Bills	Monthly	n/a	n/a	n/a
C	2, Site	Utility Bills	Quarterly	n/a	n/a	n/a
D	Whole Site	Utility Bills	Monthly	n/a	n/a	n/a
E	2, Site	Utility Bills	Monthly	n/a	n/a	n/a

As seen in **Table 7.3**, no respondent tracked electric consumption by individual equipment. Manufacturers A and D were metered for their whole site, manufacturers C and E had two meters covering their sites and manufacturer B had a meter per building at their site.

The only method used for tracking electric consumption for each respondent were their utility bills and electric energy consumption was most frequently reviewed on a monthly basis by manufacturers B, D, and E. Manufacturer C reviewed their electric consumption quarterly and manufacturer A reviewed theirs annually. As mentioned previously, manufacturer A was the only respondent that purchased natural gas; however, how the natural gas was metered, tracked, and how frequently consumption was reviewed was unknown to the interviewee.

Without tracking and maintaining accurate energy consumption data for all major functions in the facility, no baseline can be established. Gathering and analyzing this data is necessary for identifying the performance level of operations and prioritizing what needs immediate improvement (*ISO/PC 242 2011; Ross & Associates 2011; Seow & Rahimifard 2011; Worrell et al. 2010*). The data needs to be collected over time to develop a historical perspective and create context for future decisions. While utility bills do play a role in monitoring facility level energy consumption, they do not provide the necessary information for making critical energy management decisions at the process level. Preferably, operations at the process level should be sub-metered so individual activities can be measured for opportunities of improvement (*ISO/PC 242 2011; Ross & Associates 2011; Seow & Rahimifard 2011; Worrell et al. 2010*).

7.2.3 Energy Impact

When asked if rising energy expenses had a negative impact on the facility's profits all but manufacturer E said yes. Manufacturer E claimed to have no negative impact as a result of rising electricity prices at the facility. For the respondents that said yes, rising energy expenses had a negative impact on the facility's profits, a follow up question was asked about what had been done as a response to rising energy expenses. The results are presented in **Table 7.4** below.

Table 7.4: Response to rising energy expenses.

Response Choice	Mfg. A	Mfg. B	Mfg. C	Mfg. D
Increased productivity				
Improved process efficiency		x		
Increased prices to customer				
Reviewed provider's contract				
Absorbed cost and accepted lower profitability	x	x	x	x
Investigated energy-saving programs	x			
Implemented energy-saving practices and technology				

From **Table 7.4**, we see that each manufacturer who observed a negative impact due to rising energy expenses had absorbed the costs and accepted lower profitability as a consequence. Only manufacturers A and B claimed to have done more to combat the costs. Manufacturer A said they had begun investigating energy-saving practices, specifically mentioning looking at their lighting systems and investigating variable speed drives for their motors. Manufacturer B simply stated that they had been working to improve their process efficiency.

It should be noted that manufacturers A, B, C, and D did not claim to have implemented energy saving practices and technology in response to rising energy prices, however, each respondent had implemented at least three energy saving practices according to the responses in a separate question discussed below.

7.2.4 Energy Saving Practices

Respondents were then asked to select any energy related practice they've implemented from a list of common energy saving practices compiled from the literature review. The results are presented in **Table 7.5**.

Table 7.5: Implemented energy-saving practices.

Response Choice	Mfg. A	Mfg. B	Mfg. C	Mfg. D	Mfg. E
Participated in an energy audit	x	x	x	x	
Developed an explicit energy policy					
Reduced equipment settings (decreasing temperatures, pressures, or motor speeds)				x	
Made a practice of turning lights off when not in use	x	x		x	
Utilize higher efficiency lamps and/or ballasts			x		
Insulated thermal systems such as steam and water lines			x		
Participate in special utility rates					
Conduct leak detection and repair		x	x		
Made a practice of turning off equipment when not in use	x		x		
Utilize energy-efficient belts and other improved motor mechanisms		x	x		
Developed a repair/replace policy for equipment	x		x		
Other (please specify)					x

As seen in **Table 7.5**, manufacturers A, B, C, and D, had implemented at least three energy savings practices in some capacity. Those manufacturers all saw a negative impact on their profits as a result of rising energy expenses. Manufacturer E, who claimed to observe no negative impact on their profits as a result of rising energy expenses, did have capacitors installed for soft starting key equipment but had not implemented any additional energy saving practices.

The most common energy saving practice among the respondents was participating in an energy audit. It should be noted that manufacturers B, C, D, and E had previous or current business relations with a company called EnerNOC. Manufacturers B, C, and D mentioned this company when asked if they had participated in an audit. Unfamiliar with what the company provided, I contacted EnerNOC's customer service to gain a better understanding of what the company did. EnerNOC is a demand response manager that assists utility providers during energy demand peaks by notifying industrial and commercial energy users to shut down parts of their operations in return for monetary compensation. The customer service representative at EnerNOC said that while they had the capability to conduct a detailed energy audit, they did so very infrequently. The representative said that the initial process of meeting a potential customer, installing their hardware, and surveying them was referred to as an audit, however, the process is only to determine if the potential customer would be able to curtail the amount of energy consumption EnerNOC required.

It is also important to point out that while four of the five respondent had acknowledged that rising energy expenses have a negative impact on their profits, no respondent had developed an explicit energy policy for energy management. Without an explicit energy policy in place, it is likely that there are no goals or objectives, established responsibility and authority, or resources

allocated to the improvement of energy performance. This suggests that the respondents had not made a commitment to energy management, which is further supported by the lack of respondents claiming they had implemented energy saving practices in response to rising energy prices.

Each interviewee was then asked if their facility observed savings as a result of the practices they had implemented in an open answer question. Their responses are presented below.

Manufacturer A: “Bill is too high to notice”

Manufacturer B: “Can’t say I’ve looked”

Manufacturer C: “Yes, in the steam and boiler”

Manufacturer D: “Yes, we get a significant payment from EnerNOC”

Manufacturer E: “Its spread over such a long time frame, can’t tell you to be honest”

When asked if the manufacturers observed savings as a result of their energy practices, manufacturers A, B, and E had not noticed while manufacturers C and D said yes to a specific practice. Manufacturer C said they saw savings in their boiler and steam operations. As mentioned previously manufacturer C purchased biomass to fuel their boiler operations and insulated their thermal systems. This likely led to more heat retention which would lead to a lower cost of biomass fuel as they would not have needed to consume as much prior to the installation of the insulation. Manufacturer D said they received a significant amount of money from EnerNOC. Again this is part of EnerNOC’s business agreement that a customer must stop consuming a determined amount of energy during peaks in energy demand, if the customer complies they receive monetary compensation. Manufacturer D was the only respondent that currently kept this agreement with EnerNOC. Manufacturers B and C claimed that the monetary compensation from EnerNOC had been cost effective in the past but currently didn’t cover the cost of the lost production.

It is unsurprising that manufacturers A, B, and E did not observe any savings as a result of their implemented energy practices while manufacturers C and D noticed gains only in specific practices. The combination of only using utility bills as a measurement tool and the lack of explicit energy management policies, would make it difficult for any manufacturer to see energy performance improvement.

7.2.5 Lean

Respondents were asked if the facility practiced elements of lean manufacturing or the Toyota Production System in an open answer question. Their responses are presented below.

Manufacturer A: “I’ve read the books, no, we do batch production”

Manufacturer B: “Yes, we practice elements”

Manufacturer C: “Talked about it, but no”

Manufacturer D: “No”

Manufacturer E: “I’d probably say no”

As mentioned in section 2.6 of the literature review, energy management and lean manufacturing are multi-dimensional and share common key elements for success. Both require transformations in physical behaviors and company culture to achieve their greatest benefits. According to Womack (2007) it is far easier to implement a lean tool such as, value-stream mapping, setup-time reduction, 5S, standardization, and Kanban than tackling the full magnitude of the management program.

It is my opinion that lean manufacturing practices may be used to draw inferences about energy management practices due to the many similarities between the management programs. Manufacturers A, C, D, and E do not practice lean elements which further leads me to believe that

their energy saving practices were implemented simply as a “quick-fix” rather than part of an committed effort to manage their energy performance. Similarly, Espinoza et al. (2011b) concluded, based on the results from their survey of wood product manufacturers, that companies were most often implementing energy practices as one-dimensional efforts rather than long-term continuous improvement programs.

7.2.6 Information source and influence

Respondents were asked to indicate, from a list of sources, where they had received energy-saving information thus far and then to rank their chosen sources between 1-X, 1 representing the source that most influenced their energy-saving practices while X would represent the source that least influenced their energy-saving practices. The results are presented in **Table 7.6** below. Be aware that manufacturer A is not present as they did not provide an answer. Manufacturer E explained that they don’t have one particular source that is more important than another and that they use information from all of the provided sources to some degree when making decisions; thus, their response are given as “x”.

Table 7.6: Information sources and influence.

Response Choice	Mfg. B	Mfg. C	Mfg. D	Mfg. E
Colleagues within the company		1		x
Colleagues within the manufacturing sector		1	2	x
General media, such as radio, television, or internet		“Lower than 5”		x
Sector organizations	2	“Lower than 5”		x
Scientific sources, such as journals				x
Conferences and seminars	1	5		x
Information from energy providers				x
Product labels and efficiency ratings				x
Product information from dealer				x
Consultants performing energy audits		1	1	x
Government resources				x

From visual inspection of **Table 7.6**, we see that consultants performing energy audits and colleagues both within the company and the manufacturing sector are the sources of energy-saving information that most influenced the respondent’s energy-saving practices. Those sources are followed by conferences and seminars, sector organizations, and general media.

It should be noted that manufacturers C and D claimed to receive energy management information from the consultants performing energy audits were EnerNOC customers and EnerNOC’s “curtail audits” do not function as an energy audit in regards to energy management education and consultation to the customer. Unfortunately, the interview questionnaire was not designed to ask for the identity of the party responsible for conducting the energy audit. Due to this lapse of foresight, it can neither be confirmed nor denied whether EnerNOC was the sole auditor.

7.2.7 Barriers which Inhibit Implementation

Respondents were asked to consider a list of nine factors that are common barriers which impede the adoption of energy management practices, then rank them between 1-9, 1 representing the factor that most inhibits the adoption of energy-saving technologies and practices while 9 would represent the factor that least inhibits the adoption of energy-saving technologies and practices at their facility. The results are presented in **Table 7.7** below. Again manufacturer A is not present in this table because they did not provide an answer to this question. Furthermore, manufacturers B and E gave no ranking for the barriers stating that each was important, therefore, those responses are given as “x”.

Table 7.7: Common barriers and their influence.

Response Choices	Mfg. B	Mfg. C	Mfg. D	Mfg. E
Technology is inappropriate at this site				

Technical risks, such as production disruption/hassle		4.5		
Capital is directed towards other priorities	x	2	4	
Cost of identifying opportunities and analyzing cost effectiveness	x	4.5		
Lack of available capital				
Long decision chains			1	
Time is directed towards other priorities		1	4	x
Poor information quality regarding energy-saving opportunities	x	1	3	x
Lack of in-house technical expertise	x	7	2	

From visual inspection of **Table 7.7**, we see that poor information quality regarding energy saving opportunities had been chosen by each responding manufacturer and given a high importance. Time is directed towards other priorities, capital is directed towards other priorities, and lack of in-house technical expertise were the second most common barriers inhibiting the adoption of energy savings technologies and practices chosen by three of the responding manufacturers. Those were followed by cost of identifying opportunities and analyzing cost effectiveness, chosen twice, long decision chains, and technical risks which were chosen only once.

Based on the responses given in **Tables 7.6** and **7.7**, it seems that knowledge regarding energy saving has not been effectively disseminated among the respondents or their colleagues. Each of the responding manufacturers, B, C, D, and E, claimed poor information quality is an important barrier to implementing energy saving practices. At the same time manufacturers C, D, and E claimed consultants performing energy audits and colleague within the manufacturing sector were among the most influential sources for energy saving information. This further leads me to assume that manufacturers C and D did not receive an energy audit outside of the service provided by EnerNOC because a professional auditing service should be providing high information quality to its customers. Also of note, manufacturer E did not claim to have participated in an energy audit.

What's left after consultants are colleagues in the manufacturing sector, sharing information between themselves which may or may not be sound practices.

7.2.8 General Comments

Once the interviews were completed, interviewees were asked if they had anything else they wished to add. Manufacturers A and D gave the statements presented below.

Mfg. A

“As a manager you try and make the most logic choices based on what you have. Not enough time and money to do everything. However, we are still in business so we must be doing something right. I believe that is a testament to our decisions and management thus far.”

Mfg. D

“Our industry is full of old timers that do things old school. They don't like doing anything with too much tech or too much cost. I think that as younger folks enter, the industry will adopt new things faster.”

The results of these interviews suggest that while four of the five respondents have experienced negative impacts on their profits due to rising energy prices, no commitment to improving their energy performance has been made. Evidence of the lack of commitment includes no explicit energy policy, infrequent energy consumption reviews, no process level energy consumption monitoring, and the inability to recognize savings from implemented energy practices.

According to the respondents, poor information quality about energy savings was the most common barrier to implementing energy savings practices and technologies, followed by time is directed towards other priorities and capital is directed towards other priorities. In 2003,

Emplaincourt et al. reported that the most common reasons for failure to implement energy saving recommendations among wood furniture manufacturers was a lack of time to plan and implement recommendations and a lack of funds didn't allow money to be spent. One common sentiment shared by each of the five manufacturers in the current study was that money was not and would not be an issue if the manufacturers decided to invest it in energy performance.

The combination of the lack of commitment to energy performance and the reported barriers to implementation of energy practices lead me to believe that the dissemination of energy performance knowledge and benefits is a problem. It makes sense that little time, funds, or efforts are directed towards energy management, when the information quality regarding energy savings is perceived as poor.

While these few respondents do not represent the U.S. wood products industry as a whole, these results indicate that efforts should be made to better inform and educate wood products manufacturers about energy management, its benefits, and the projected future of energy prices and demand. Industrial energy prices are projected to increase from now through the year 2040 (*U.S. EIA 2016b*). Energy demand is likely to increase globally as China's and India's infrastructure grow (*OECD/IEA 2015*). The U.S. wood products industry must find ways to remain competitive and given the lack of ability to pass on the price of raw materials to consumers and low-cost labor is driving production overseas, energy management has become an important method for obtaining a competitive advantage for remaining U.S. wood product manufacturers (*Ahmad 2014; Espinoza et al 2011a; Gazo & Quesada 2005*).

CHAPTER 8 – SUMMARY & CONCLUSIONS

8.1 Summary

Historically, energy used for manufacturing was a small portion of the total cost and was accepted as a normal part of business (*Mate 2002; Sciortino et al. 2009; Wengert & Meyer 1992*), however, more attention is being given to energy management as increasing energy prices are impacting profit margins (*Devaru et al. 2013, Espinoza et al. 2011a; Lin et al. 2012; Sciortino et al. 2009*). Energy prices and demand are projected to increase globally and markets become more competitive nationally and internationally; the U.S. wood products industry must find ways to remain relevant. Given the lack of ability to pass on the price of raw materials to consumers and the quest for low-cost labor has driven much production overseas, energy management an excellent method for creating a competitive advantage for remaining U.S. wood product manufacturers (*Ahmad 2014; Espinoza et al 2011a; Gazo & Quesada 2005*).

The author has compiled and analyzed energy recommendations in the IAC database, identified lean-based energy recommendations, and provided insight into the practices and perspectives of a small sample of U.S. wood product manufacturers to present the industry with information about which energy management practices should be considered to best reduce energy costs, thus improving its competitiveness.

Specifically, this research addressed four research objectives:

- 1) Identify and rank energy recommendations given to wood products manufactures by implementation cost, savings, payback period, and implementation frequency.

- 2) Compare implemented energy recommendations by cost, savings, and payback criteria between wood and non-wood manufacturers and between primary and secondary wood manufacturers.
- 3) Identify energy recommendations from the IAC database, implemented by wood products manufacturers, which incorporate lean manufacturing practices or principles.
- 4) Provide insight on the energy consumption, energy management practices, and perspectives of wood product manufacturers regarding energy management based on a comparative case study.

8.2 Conclusions

1) Energy recommendations present in the least cost, greatest savings, and shortest payback period rankings had very low implementation rates and subsequently were infrequently present in the most frequently implemented ranking among wood product manufacturers. These findings suggest wood products manufacturers were not focused on implementing energy recommendations specifically based on cost, savings, and payback criteria.

Combustion and thermal systems recommendations should save the greatest amount of energy for wood product manufacturers with those operations; however, those savings may not be obvious. Electrical power, motor systems, operations, and building and grounds recommendations have the greatest potential for fitting well and producing effective visible results for the U.S. wood products industry on a day-to-day basis.

2) Twelve energy recommendations were found to be statistically significantly different at $\alpha = 0.05$ in at least one criteria: cost, savings, or payback period between wood and non-wood manufacturers. However, there was little practical difference, in terms of payback period, between wood and non-wood manufacturers.

Fifteen energy recommendations were found to be statistically significantly different at $\alpha = 0.05$ in at least one criteria: cost, savings, or payback period between primary and secondary wood manufacturers. However, only two recommendations, 2.2131 (Insulate steam / hot water lines) and 2.4151 (Develop a repair/replace policy), had practical differences, large payback periods of 2.17 and 1.70 years, respectively, between primary and secondary wood manufacturers.

3) Twenty-four energy recommendations were classified as lean-based energy recommendations using the lean tools methodology. From the IAC database alone, there was no clear superiority in terms of lower costs, greater savings, or shorter payback periods between the 24 lean-based energy recommendations and simple energy recommendations as productivity gains are not included in the IAC database. Each of the 24 recommendations have the potential to increase productivity while simultaneously saving energy if implemented according to lean principles.

4) Four of the five respondents acknowledged that rising energy expenses have a negative impact on their profits, however no respondent claimed to have developed an explicit energy policy for energy management. Each manufacturer had implemented at least one energy management practice, however only two manufacturers noticed any gains as a result. This is unsurprising as no respondent monitored energy consumption at an equipment or process level, making it difficult for any person to see energy performance improvement.

A combination of the lack of commitment to energy performance improvement and the reported barriers of implementation among the respondents suggest that the dissemination of energy management knowledge and benefits is a problem. Efforts to better inform and educate the

wood products industry about energy is likely necessary to combat the lack of commitment and poor information quality common among the small sample of participants.

8.3 Significance

Studies have shown that the management of energy consumption and efficiency is an important component of day-to-day wood product manufacturing operations; an importance which is projected to increase as concerns about energy demand and prices continue to grow and manufacturers' ability to affect raw material and labor costs remain difficult. Analysis of the IAC database for energy recommendations suggests that the largest energy savings for the wood products industry would come from energy management practices aimed at combustion (boiler) and thermal (dry kiln) systems for manufacturers with those operations. However, the analysis and case study results suggest that wood products manufacturers were not implementing energy-saving recommendations based on least cost, greatest savings, or shortest payback period alone but that they are most likely implementing recommendations based on the simplicity and gains observable in utility billing. For example, "make a practice of turning off lights when not needed" (present in the most frequently implemented ranking) is an easy practice that can even be automated, whereas "use power during off-peak periods" (present in least cost, greatest savings, and shortest payback ranking; but implemented once) requires scheduling and potential personnel changes that are much more difficult to implement. For the average U.S. wood product manufacturer that is looking for quick and painless energy management, the recommendations present in the most frequently implemented ranking are excellent practices that are fairly simple to implement, likely to positively impact utility bills, and should work for the average manufacturer as they have been implemented across the nation. However it is clear that those looking to significantly reduce energy costs and

hopefully increase competitiveness should focus on recommendations related to combustion and thermal systems.

8.4 Limitations

The IAC database is an excellent resource containing large amounts of information on energy saving practices for manufacturers across the nation but it is not without its limitations. The most influential limitation was missing data, especially from earlier dated entries, which limited which variables could be used in statistical analysis and relegated the classification of manufacturers to the Standard Industrial Classification (SIC), an antiquated system.

Identifying lean-based energy recommendations was based on the definitions and wording of the lean tools described in Kirby and Green (2003). If other sources or wording of lean tools are used the results may differ.

The sample size for the investigating energy consumption, energy management practices, and perspectives of wood product manufacturers regarding energy management, is a significant limiting factor for this analysis; therefore the results should be considered preliminary and a larger sample sized used before extrapolating the results found to the industry as a whole.

8.5 Future Work

The IAC database alone, does not contain enough information to statistically determine which variables may influence differences between manufacturing groups or definitively determine if any lean-based energy recommendations have superior savings or payback periods due to missing data and unaccounted productivity gains, respectively.

If future work is conducted in the interest of identifying influencing factors contributing to the differences of energy recommendations between manufacturing groups or identifying lean-based energy recommendations that have both productivity and energy performance gains, I suggest collecting your own data of manufacturers to assure all potentially relevant information is available. Furthermore, it is my opinion that wood manufactures and non-wood manufacturers encompassed such a large sample of manufacturers with varying degrees of operations, energy consumption, market maturities, and so on, that subtle differences between the two could not be exposed. Creating more focused manufacturing groups by similar key factors such as industry maturity, reliance on agricultural materials, or small profit margins may reveal more telling results in any future comparison research.

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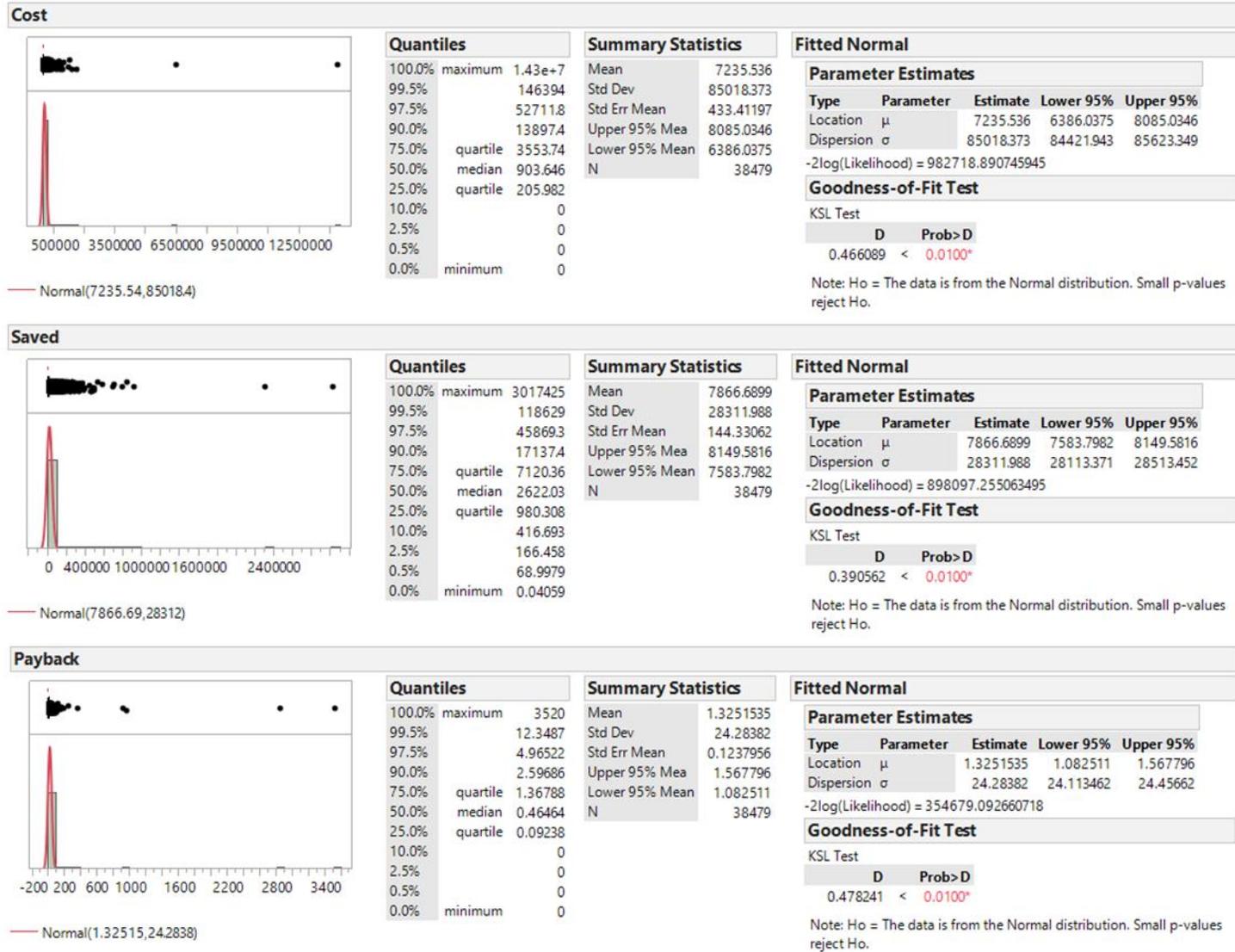
APPENDIX A

VBA code for merging the ASSESS and RECC worksheets.

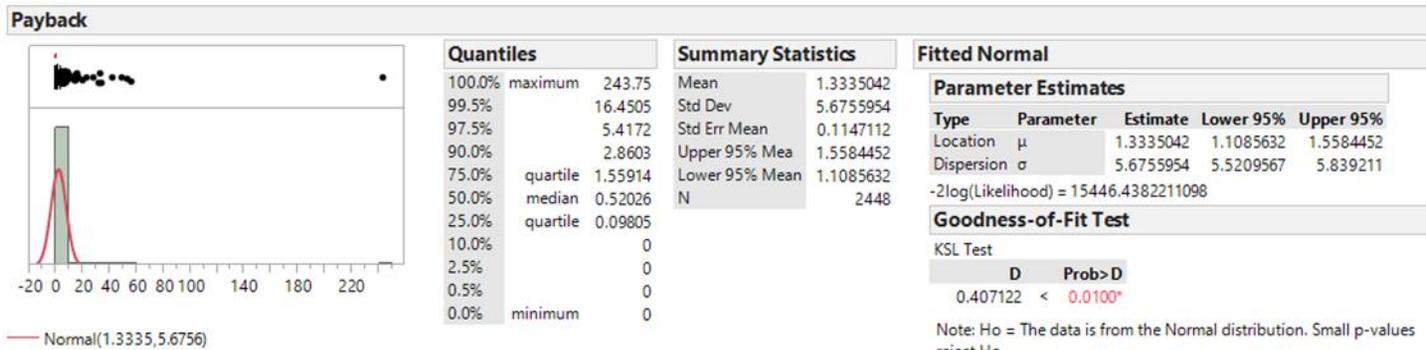
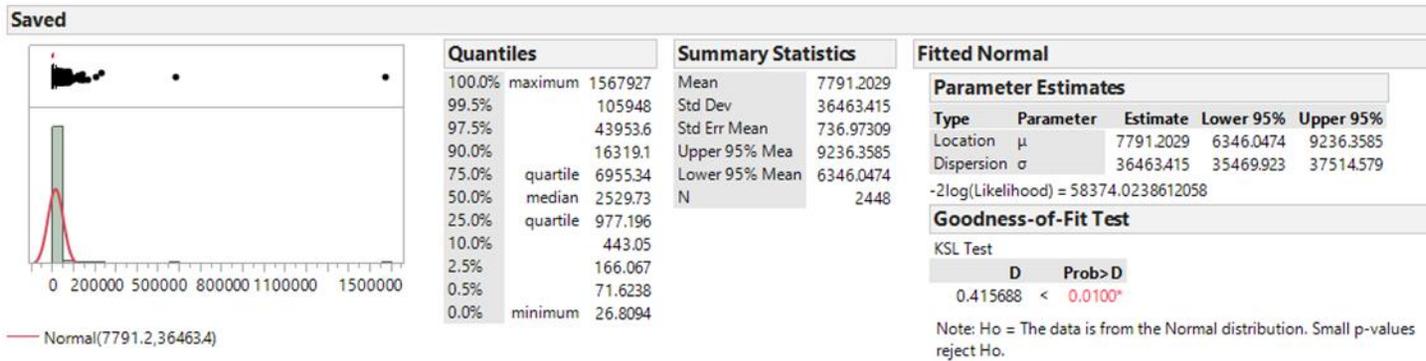
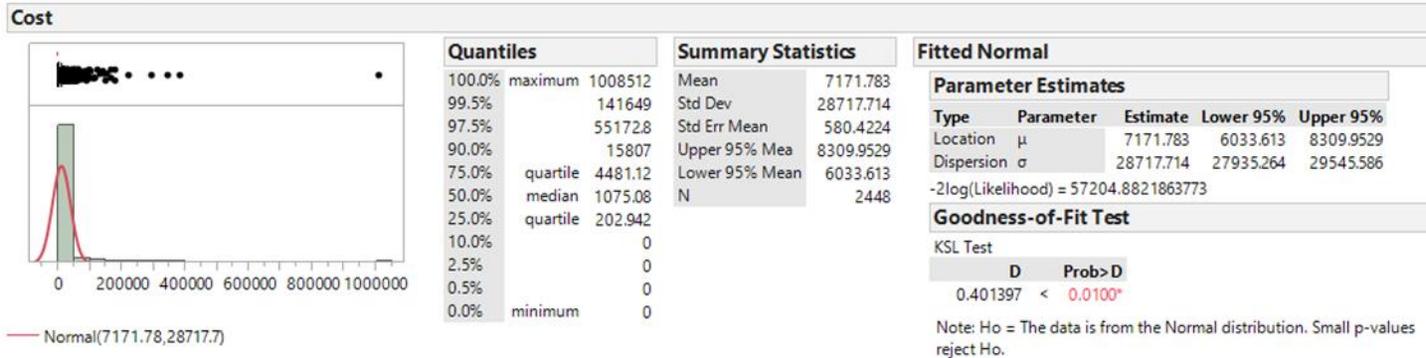
```
Sub Combo()  
    'must have empty sheet open'  
    x = 2  
    y = 2  
  
    Do While Sheets("RECC").Cells(x, 1) <> ""  
        If Sheets("RECC").Cells(x, 1) = Sheets("ASSESS").Cells(y, 1) Then  
            Sheets("ASSESS").Rows(y).Copy  
            Sheets("Sheet1").Cells(x, 1).Activate  
            ActiveSheet.Paste  
  
            Else  
  
            y = y + 1  
            Sheets("ASSESS").Rows(y).Copy  
            Sheets("Sheet1").Cells(x, 1).Activate  
            ActiveSheet.Paste  
        End If  
        x = x + 1  
    Loop  
End Sub
```

APPENDIX B

Wood vs. non-wood goodness of fit tests.



Primary vs. secondary goodness of fit tests.



APPENDIX C

The 192 unique IAC recommendations that have been implemented by wood products manufacturers, divided into focus areas.

Combustion Systems

ARC2	Description
2.1111	Control pressure on steamer operations
2.1113	Reduce combustion air flow to optimum
2.1114	Limit and control secondary combustion air in furnace
2.1116	Improve combustion control capability
2.1121	Use insulation in furnaces to facilitate heating / cooling
2.1122	Re-size charging openings or add a movable door on equipment
2.1123	Install automatic stack damper
2.1131	Repair faulty insulation in furnaces, boilers, etc.
2.1132	Repair faulty louvers and dampers
2.1133	Adjust burners for efficient operation
2.1213	Direct warmest air to combustion intake
2.1221	Replace obsolete burners with more efficient ones
2.1222	Install turbulators
2.1223	Install smaller boiler (increase high fire duty cycle)
2.1224	Replace boiler
2.1231	Establish burner maintenance schedule for boilers
2.1232	Keep boiler tubes clean
2.1233	Analyze flue gas for proper air/fuel ratio
2.1241	Reduce excessive boiler blowdown
2.1243	Use heat from boiler blowdown to preheat boiler feed water
2.1311	Replace electrically-operated equipment with fossil fuel equipment
2.1321	Replace fossil fuel equipment with electrical equipment
2.1331	Burn a less expensive grade of fuel
2.1335	Replace gasoline with diesel, LPG, or natural gas
2.1336	Install equipment to utilize waste fuel
2.1392	Replace purchased steam with other energy source

Thermal Systems

ARC2	Description
2.2113	Repair or replace steam traps
2.2121	Increase amount of condensate returned
2.2122	Install / repair insulation on condensate lines
2.2123	Insulate feedwater tank
2.2126	Lower operating pressure of condenser (steam)
2.2127	Flash condensate to produce lower pressure steam
2.2128	Use steam condensate for hot water supply (non-potable)
2.2131	Insulate steam / hot water lines
2.2132	Repair faulty insulation on steam lines
2.2133	Repair leaks in lines and valves
2.2135	Repair and eliminate steam leaks
2.2153	Close off unneeded steam lines
2.2162	Reduce excess steam bleeding

2.2163	Use minimum steam operating pressure
2.2211	Use optimum temperature
2.2314	Replace heat treating oven with more efficient unit
2.2411	Use waste heat from hot flue gases to preheat combustion air
2.2412	Use flue gas heat to preheat boiler feedwater
2.2424	Use heat in flue gases to preheat products or materials
2.2425	Use flue gases to heat process or service water
2.2426	Use waste heat from flue gases to heat space conditioning air
2.2432	Recover heat from oven exhaust / kilns
2.2434	Recover heat from air compressor
2.2437	Recover waste heat from equipment
2.2441	Preheat boiler makeup water with waste process heat
2.2443	Re-use or recycle hot or cold process exhaust air
2.2444	Use hot process fluids to preheat incoming process fluids
2.2445	Recover heat from exhausted steam
2.2446	Recover heat from hot waste water
2.2511	Insulate bare equipment
2.2512	Increase insulation thickness
2.2513	Cover open tanks with floating insulation
2.2514	Cover open tanks
2.2522	Isolate hot or cold equipment
2.2531	Re-size charging openings or add movable cover or door
2.2532	Use only amount of air necessary to prevent explosion hazard
2.2622	Replace existing chiller with high efficiency model
2.2625	Chill water to the highest temperature possible
2.2627	Use multiple-effect evaporators
2.2628	Utilize a less expensive cooling method
2.2711	Utilize outside air instead of conditioned air for drying

Electric Power

ARC2	Description
2.3131	Reschedule plant operations or reduce load to avoid peaks
2.3132	Recharge batteries on during off-peak demand periods
2.3133	Consider three or four days around-the-clock operation rather than one or two shifts per day
2.3134	Shift from daytime to nighttime operation
2.3135	Schedule routine maintenance during non-operating periods
2.3137	Use power during off-peak periods
2.3191	Use demand controller or load shedder
2.3192	Use fossil fuel powered generator during peak demand periods
2.3211	Use power factor controllers
2.3212	Optimize plant power factor
2.3321	Use steam pressure reduction to generate power
2.3322	Use existing dam to generate electricity
2.3411	Replace electric motors with back pressure steam turbines and use exhaust steam for process heat
2.3412	Use waste heat to produce steam to drive a steam turbine generator
2.3414	Burn waste to produce steam to drive a steam turbine generator set and use steam exhaust for heat
2.3415	Use a fossil fuel engine to cogenerate electricity or motive power; and utilize heat

Motor Systems

ARC2	Description
2.4111	Utilize energy-efficient belts and other improved mechanisms

2.4112	Install soft-start to eliminate nuisance trips
2.4113	Install motor voltage controller on lightly loaded motors
2.4131	Replace over-size motors and pumps with optimum size
2.4132	Size electric motors for peak operating efficiency
2.4133	Use most efficient type of electric motors
2.4141	Use multiple speed motors or AFD for variable pump, blower and compressor loads
2.4142	Use adjustable frequency drive to replace motor-generator set
2.4143	Use adjustable frequency drive to replace throttling system
2.4144	Use adjustable frequency drive to replace mechanical drive
2.4151	Develop a repair/replace policy
2.4156	Establish a preventative maintenance program
2.4157	Establish a predictive maintenance program
2.4221	Install compressor air intakes in coolest locations
2.4222	Install adequate dryers on air lines to eliminate blowdown
2.4223	Install direct acting units in place of compressed air pressure system in safety system
2.4224	Upgrade controls on compressors
2.4225	Install common header on compressors
2.4226	Use / purchase optimum sized compressor
2.4227	Use compressor air filters
2.4231	Reduce the pressure of compressed air to the minimum required
2.4232	Eliminate or reduce compressed air used for cooling, agitating liquids, moving product, or drying
2.4233	Eliminate permanently the use of compressed air
2.4235	Remove or close off unneeded compressed air lines
2.4236	Eliminate leaks in inert gas and compressed air lines/ valves
2.4238	Do not use compressed air for personal cooling
2.4311	Recover mechanical energy
2.4312	Improve lubrication practices
2.4313	Provide proper maintenance / of motor driven equipment
2.4314	Use synthetic lubricant
2.4321	Upgrade obsolete equipment
2.4322	Use or replace with energy efficient substitutes
2.4323	Use optimum size and capacity equipment
2.4324	Replace hydraulic / pneumatic equipment with electric equipment
2.4325	Upgrade conveyors

Industrial Design

ARC2	Description
2.5115	Reposition oven walls to reduce heated space
2.5121	Redesign flow to minimize mass transfer length
2.5122	Replace high resistance ducts, pipes, and fittings
2.5123	Reduce fluid flow rates
2.5125	Size air handling grills/ duct/s coils to minimize air resistance
2.5194	Redesign process
2.5195	Change product design to reduce energy requirements

Operations

ARC2	Description
2.6121	Reduce hot water temperature to the minimum required
2.6122	Adjust vents to minimize energy use
2.6123	Remove unneeded service lines to eliminate potential leaks
2.6124	Establish equipment maintenance schedule

2.6125	Keep equipment clean
2.6126	Keep solid fuels / raw materials dry
2.6127	Maintain air filters by cleaning or replacement
2.6211	Conserve energy by efficient use of vending machines
2.6212	Turn off equipment during breaks, reduce operating time
2.6213	Turn off steam / hot water lines leading to space heating units
2.6214	Shut off pilots in standby equipment
2.6218	Turn off equipment when not in use
2.6221	Use most efficient equipment at its maximum capacity and less efficient equipment only when necessary
2.6222	Use drying oven (batch type) on alternate days or other optimum schedule to run equipment with full loads
2.6225	Eliminate third shift
2.6231	Utilize controls to operate equipment only when needed
2.6232	Install set-back timers
2.6242	Minimize operation of equipment maintained in standby condition

Building & Grounds

ARC2	Description
2.7111	Reduce illumination to minimum necessary levels
2.7112	Reduce exterior illumination to minimum safe level
2.7121	Utilize daylight whenever possible in lieu of artificial light
2.7122	Disconnect ballasts
2.7124	Make a practice of turning off lights when not needed
2.7131	Add area lighting switches
2.7132	Install timers on light switches in little used areas
2.7133	Use separate switches on perimeter lighting which may be turned off when natural light is available
2.7134	Use photocell controls
2.7135	Install occupancy sensors
2.7141	Lower light fixtures in high ceiling areas
2.7142	Utilize higher efficiency lamps and/or ballasts
2.7143	Use more efficient light source
2.7144	Install spectral reflectors / delamp
2.7145	Install skylights
2.7221	Lower temperature during the winter season and vice-versa
2.7222	Air condition only space in use
2.7223	Condition smallest space necessary
2.7224	Reduce space conditioning during non-working hours
2.7225	Close outdoor air dampers during warm-up / cool-down periods
2.7226	Use computer programs to optimize hvac performance
2.7228	Avoid introducing hot, humid, or dirty air into hvac system
2.7231	Use radiant heater for spot heating
2.7232	Replace existing hvac unit with high efficiency model
2.7241	Install outside air damper / economizer on hvac unit
2.7243	Improve air circulation with destratification fans / other methods
2.7244	Revise smoke cleanup from operations
2.7261	Install timers and/or thermostats
2.7312	Minimize use of outside make-up air for ventilation except when used for economizer cycle
2.7313	Recycle air for heating, ventilation and air conditioning
2.7314	Reduce ventilation air

2.7316	Centralize control of exhaust fans to ensure their shutdown, or establish program to ensure manual shutdown
2.7441	Replace broken windows and/or window sash
2.7442	Keep doors and windows shut when not on use
2.7443	Air seals around truck loading dock doors
2.7444	Close holes and openings in building such as broken windows
2.7445	Install weather stripping on windows and doors
2.7447	Install vinyl strip / high speed / air curtain doors
2.7491	Insulate glazing, walls, ceilings, and roofs
2.7492	Use proper thickness of insulation on building envelope
2.7494	Install storm windows and doors

Ancillary Costs

ARC2	Description
2.8111	Check for accuracy of utility meters
2.8112	Combine utility meters
2.8113	Purchase gas directly from a contract gas supplier
2.8114	Change rate schedules or other changes in utility service
2.8121	Apply for tax-free status for energy purchases
2.8123	Pay utility bills on time
2.8211	Consolidate freight shipments and/or deliveries
2.8223	Add air shields to trucks to increase fuel mileage

APPENDIX D

Recruitment letter.



Sustainable Biomaterials
Brooks Center (0503), 1650 Research Center Drive
Blacksburg, Virginia 24061
Phone: 540-557-7805
E-mail: baumanmj@vt.edu
www.sblo.vt.edu

Date

Name
Company
Street
City, State ZIP Code

Dear Name,

During the last decade the wood products industry has faced economic recession, increasing energy costs, and global competition. This combination of factors, among others, have put a measurable burden on the industry. Companies continue to improve products and processes, however, they may be missing opportunities to reduce costs through energy management practices.

Virginia Tech is conducting research to identify, rank, and compare energy-saving practices, implemented by the wood products industry, which have the greatest impact on factors such as implementation costs, savings, and payback period. Included in this research are questions about wood products manufacturers' current practices and views regarding energy management.

We are asking for your help on this project by agreeing to participate in a brief interview, 20-30 minutes, regarding your company's energy use, energy practices, and perceptions toward energy management. Results from this interview will provide valuable information regarding energy management practices, implementation, and potential for improvement. Please be assured that any sensitive information will be treated with complete confidentiality. Your name and your company name will never be identified in the study results. Only study codes, i.e., Company X, will be reported in the results.

Thank you very much for your time and assistance. Should you have any questions or wish to schedule a time for the interview, please contact me by email: baumanmj@vt.edu (preferred), or by phone: 540-557-7805.

Sincerely,

Michael Bauman
Graduate Research Assistant

Invent the Future

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
An equal opportunity, affirmative action institution

APPENDIX E

Interview questionnaire.

Study Code: _____

1) Please choose a category that best represents the main product produced by this facility:
(check one)

- Sawmills and Planing Mills
- Millwork and Cabinetry
- Veneer, Plywood, and Structural Wood
- Wood Containers and Pallets
- Wood Buildings and Mobile Homes
- Miscellaneous Wood Products
- Wood Household Furniture
- Wood Office Furniture, Store Fixtures, and Lockers
- Other *(please specify)*

2) Total area used for production and office purposes at this facility: _____

3) Number of employees at this facility: _____

4) Annual production hours of this facility: _____

5) Annual sales from this facility: _____

6) Annual electric consumption: _____

7) Annual natural gas consumption: _____

8) Annual peak demand electric consumption: _____

9) Please indicate which type(s) of energy is purchased by this facility:
(choose all that apply)

- Electricity only
- Natural gas only
- Both electricity and natural gas
- Other *(please specify)*

10) At what level is energy consumption generally metered?

- | | |
|---|---|
| <i>Electricity</i> | <i>Natural gas</i> |
| <input type="checkbox"/> Whole site | <input type="checkbox"/> Whole site |
| <input type="checkbox"/> Building | <input type="checkbox"/> Building |
| <input type="checkbox"/> Individual equipment | <input type="checkbox"/> Individual equipment |

11) By what method is energy consumption tracked?

- | | |
|---|---|
| <i>Electricity</i> | <i>Natural gas</i> |
| <input type="checkbox"/> Utility bills | <input type="checkbox"/> Utility bills |
| <input type="checkbox"/> Meters | <input type="checkbox"/> Meters |
| <input type="checkbox"/> Other (please specify) | <input type="checkbox"/> Other (please specify) |

12) How frequently is energy consumption generally reviewed?

- | | |
|-----------------------------------|-----------------------------------|
| <i>Electricity</i> | <i>Natural gas</i> |
| <input type="checkbox"/> Annually | <input type="checkbox"/> Annually |
| <input type="checkbox"/> Monthly | <input type="checkbox"/> Monthly |
| <input type="checkbox"/> Weekly | <input type="checkbox"/> Weekly |
| <input type="checkbox"/> Daily | <input type="checkbox"/> Daily |

13) Have rising energy expenses had a negative impact on this facility's profits? Yes No

14) If yes, what has been done in response? If no, continue to question 15.

(choose all that apply)

- Increased productivity
- Investigating energy-saving programs
- Improved process efficiency
- Increased prices to customers
- Absorbed costs and accepted lower profitability
- Reviewed providers' contract
- Implemented energy-saving practices and technology

15) Has this facility implemented any of the following energy-saving practices?

(choose all that apply)

- Participated in an energy audit
- Developed an explicit energy policy
- Reduced equipment settings (decreasing temperatures, pressures, or motor speeds)
- Made a practice of turning lights off when not in use
- Utilize higher efficiency lamps and or ballasts
- Insulated thermal systems such as steam and water lines
- Participate in special utility rates
- Conduct leak detection and repairs
- Made a practice of turning off equipment when not in use
- Utilize energy-efficient belts and other improved motor mechanisms
- Developed a repair/replace policy for equipment
- Other *(please specify)*

16) Has this facility observed savings resulting from any of these practices?

(open answer)

17) Does this facility practice elements of Lean Manufacturing or the Toyota Production System?

(open answer)

18) Please indicate, from among the following sources, where you have received energy-saving information thus far.

(choose all that apply)

- Colleagues within the company _____
- Colleagues within the manufacturing sector _____
- General media, such as radio, television, or internet _____
- Sector organizations _____
- Scientific sources, such as journals _____
- Conferences and seminars _____
- Information from energy providers _____
- Product labels and efficiency ratings _____
- Product information from dealer _____
- Consultants performing energy audits _____
- Government resources _____

19) Please rank the sources chosen above 1-X, 1 representing the source that *most influences* your energy-saving practices while X would represent the source that *least influences* your energy-saving practices at this facility.

20) Please consider each of the following factors then rank them 1-9, 1 representing the factor that *most inhibits* the adoption of energy-saving technologies and practices while 9 would represent the factor that *least inhibits* the adoption of energy-saving technologies and practices at this facility.

- _____ Technology is inappropriate at this site
- _____ Technical risks, such as production disruption/hassle
- _____ Capital is directed towards other priorities
- _____ Cost of identifying opportunities and analyzing cost effectiveness
- _____ Lack of available capital
- _____ Long decision chains
- _____ Time is directed towards other priorities
- _____ Poor information quality regarding energy saving opportunities
- _____ Lack of in-house technical expertise

APPENDIX F

Average values for wood vs. non-wood manufacturers. Values in bold represent the significantly different values.

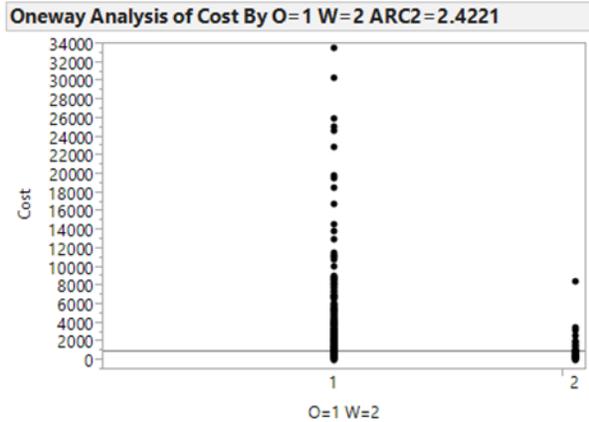
ARC2	Cost Non-Wood	Cost Wood	Saved Non-Wood	Saved Wood	Payback Non-wood	Payback Wood
2.2434	\$3,684.20	\$2,104.20	\$6,079.10	\$3,040.32	0.98	1.15
2.4111	\$2,298.17	\$3,024.00	\$4,206.34	\$5,016.05	0.63	0.70
2.4133	\$13,634.97	\$17,717.78	\$6,465.91	\$5,961.40	3.82	3.56
2.4141	\$34,628.35	\$53,037.67	\$23,015.11	\$33,859.93	1.94	1.68
2.4221	\$1,075.81	\$698.36	\$2,597.81	\$1,724.93	0.80	0.75
2.4231	\$1,243.84	\$1,388.34	\$4,618.03	\$3,510.72	0.77	0.29
2.4232	\$4,448.30	\$1,838.34	\$9,966.12	\$7,551.45	0.70	0.75
2.4236	\$1,525.07	\$2,975.22	\$7,095.83	\$7,911.86	0.37	0.46
2.6232	\$1,571.36	\$1,621.34	\$4,130.53	\$8,198.67	0.61	0.30
2.7135	\$3,056.25	\$7,388.21	\$3,122.79	\$3,994.08	1.43	1.73
2.7142	\$13,869.81	\$9,900.59	\$7,504.51	\$5,121.25	2.58	2.79
2.8121	\$1,140.34	\$1,666.24	\$13,428.16	\$7,150.98	0.20	0.31

Average values primary vs secondary manufacturers. Values in bold represent the significantly different values.

ARC2	Cost Primary	Cost Secondary	Saved Primary	Saved Secondary	Payback Primary	Payback Secondary
2.1233	\$7,319.18	\$2,082.95	\$25,106.98	\$6,053.44	0.51	1.16
2.2131	\$3,110.67	\$17,862.04	\$3,445.20	\$9,276.01	0.98	3.15
2.3131	\$1,484.20	\$1,203.55	\$23,864.03	\$4,136.66	0.30	0.44
2.3212	\$20,076.11	\$12,207.29	\$15,765.62	\$8,542.11	1.69	1.68
2.4111	\$3,930.26	\$1,431.91	\$6,375.72	\$2,627.46	0.75	0.61
2.4133	\$25,042.21	\$6,622.36	\$7,622.97	\$3,444.37	3.44	3.73
2.4151	\$2,530.12	\$6,474.03	\$6,402.46	\$3,587.64	0.55	2.25
2.4221	\$640.15	\$735.98	\$2,240.59	\$1,391.73	0.69	0.79
2.4236	\$4,695.02	\$1,416.65	\$11,460.11	\$4,696.26	0.49	0.43
2.4314	\$196.41	\$816.19	\$2,778.87	\$1,427.38	0.37	0.57
2.6212	\$455.88	\$1,382.84	\$4,494.08	\$5,194.29	0.11	0.47
2.6218	\$4,539.68	\$1,249.13	\$9,285.38	\$3,923.89	0.67	0.36
2.6232	\$1,755.95	\$1,277.35	\$9,746.93	\$4,241.99	0.20	0.53
2.7135	\$9,181.34	\$5,520.36	\$5,720.88	\$2,195.34	1.75	1.72
2.8121	\$1,979.33	\$1,318.36	\$2,591.28	\$12,217.33	0.32	0.29

APPENDIX G

Wood vs Non-wood Cost, Wilcoxon Results



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

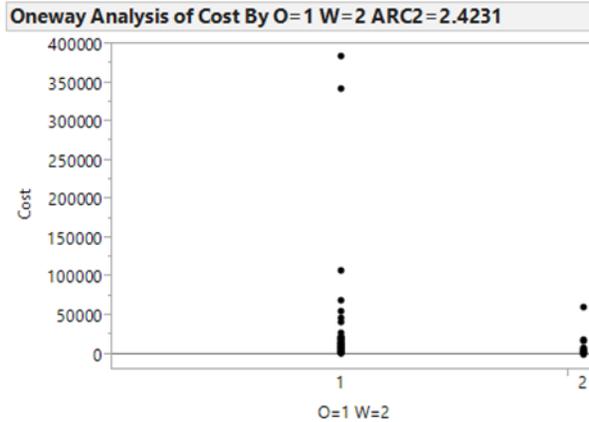
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0
1	2171	2493120	2473855	1148.37	2.900
2	107	102661	121927	959.45	-2.900

2-Sample Test, Normal Approximation

S	Z	Prob> Z
102661	-2.90046	0.0037*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
8.4131	1	0.0037*



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

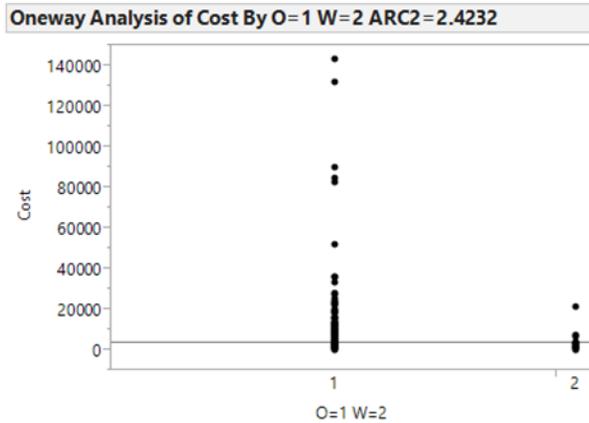
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0
1	1843	1790240	1803376	971.37	-2.301
2	113	123706	110571	1094.74	2.301

2-Sample Test, Normal Approximation

S	Z	Prob> Z
123706	2.30142	0.0214*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
5.2969	1	0.0214*



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

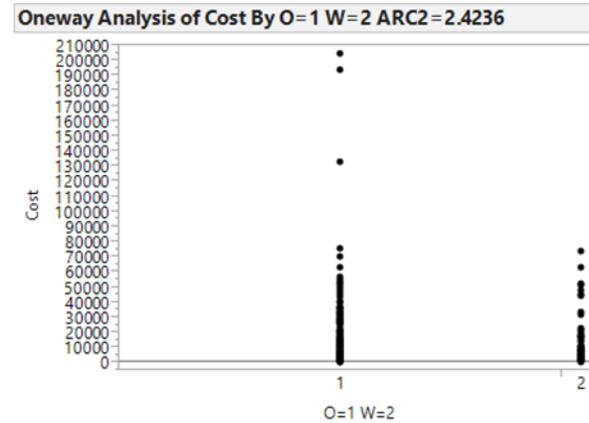
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0
1	516	146228	144222	283.388	1.997
2	42	9733.00	11739.0	231.738	-1.997

2-Sample Test, Normal Approximation

S	Z	Prob> Z
9733	-1.99689	0.0458*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
3.9896	1	0.0458*



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0
1	5443	1.59e+7	1.61e+7	2928.42	-5.646
2	488	1651950	1447408	3385.14	5.646

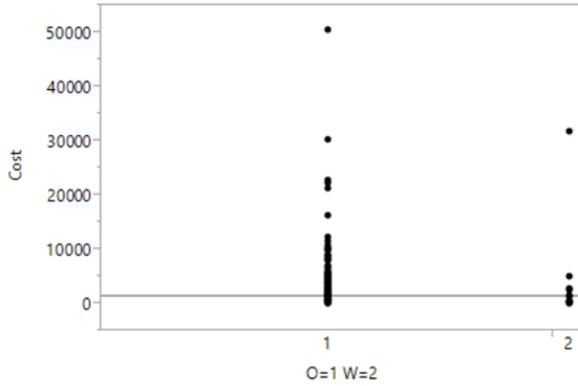
2-Sample Test, Normal Approximation

S	Z	Prob> Z
1651949.5	5.64564	<.0001*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
31.8734	1	<.0001*

Oneway Analysis of Cost By O=1 W=2 ARC2=2.6232



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		
			Score	Score Mean	(Mean-Mean0)/Std0
1	468	118867	117234	253.989	2.101
2	32	6383.00	8016.00	199.469	-2.101

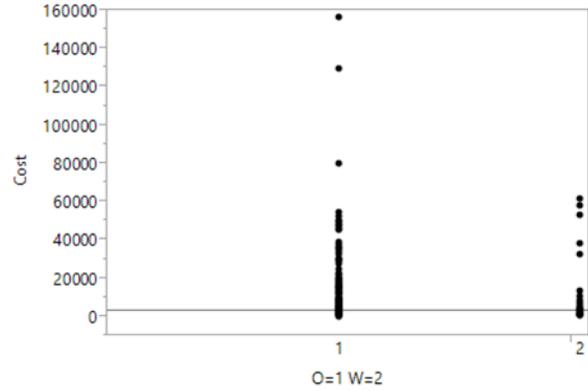
2-Sample Test, Normal Approximation

S	Z	Prob> Z
6383	-2.10128	0.0356*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
4.4181	1	0.0356*

Oneway Analysis of Cost By O=1 W=2 ARC2=2.7135



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		
			Score	Score Mean	(Mean-Mean0)/Std0
1	1244	798560	804868	641.929	-2.460
2	49	38011.5	31703.0	775.745	2.460

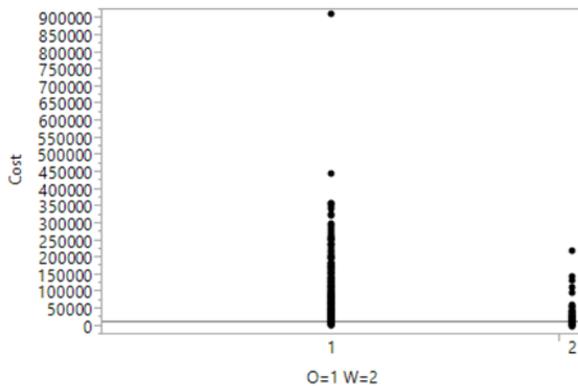
2-Sample Test, Normal Approximation

S	Z	Prob> Z
38011.5	2.46041	0.0139*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.0546	1	0.0139*

Oneway Analysis of Cost By O=1 W=2 ARC2=2.7142



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		
			Score	Score Mean	(Mean-Mean0)/Std0
1	5885	1.83e+7	1.82e+7	3111.57	2.803
2	308	868131	953876	2818.61	-2.803

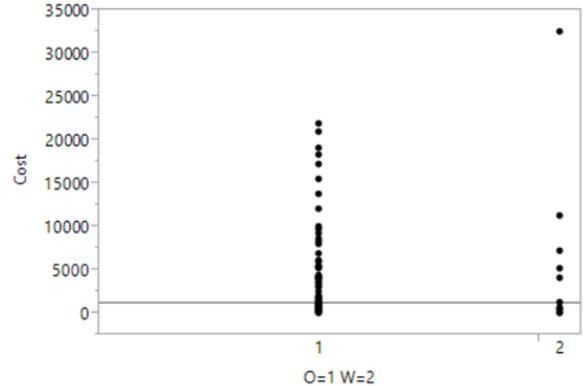
2-Sample Test, Normal Approximation

S	Z	Prob> Z
868131	-2.80342	0.0051*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
7.8593	1	0.0051*

Oneway Analysis of Cost By O=1 W=2 ARC2=2.8121



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		
			Score	Score Mean	(Mean-Mean0)/Std0
1	394	87475.5	85301.0	222.019	3.021
2	38	6052.50	8227.00	159.276	-3.021

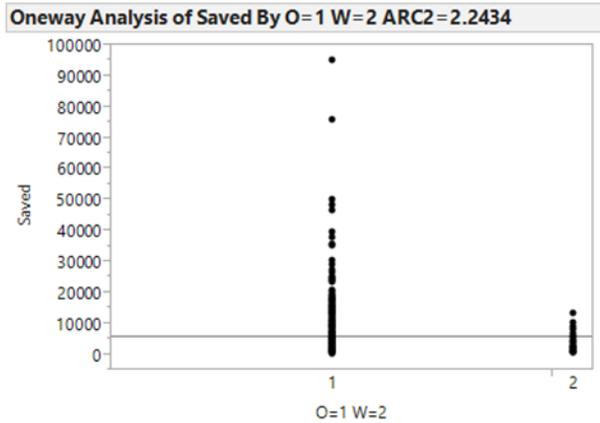
2-Sample Test, Normal Approximation

S	Z	Prob> Z
6052.5	-3.02072	0.0025*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
9.1289	1	0.0025*

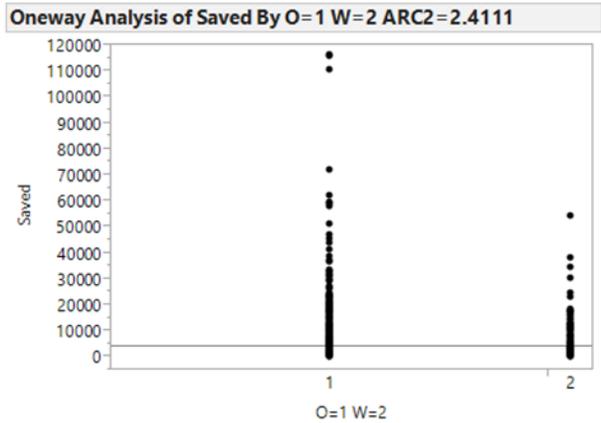
Wood vs Non-wood Saved, Wilcoxon Results



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)						
Expected						
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0	
1	431	103352	101501	239.796	2.279	
2	39	7333.00	9184.50	188.026	-2.279	

2-Sample Test, Normal Approximation		
S	Z	Prob> Z
7333	-2.27885	0.0227*

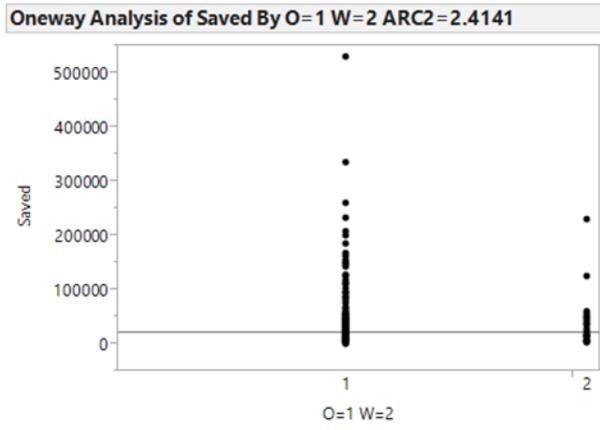
1-way Test, ChiSquare Approximation		
ChiSquare	DF	Prob>ChiSq
5.1960	1	0.0226*



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)						
Expected						
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0	
1	1984	2144929	2171488	1081.11	-3.091	
2	204	249838	223278	1224.69	3.091	

2-Sample Test, Normal Approximation		
S	Z	Prob> Z
249837.5	3.09096	0.0020*

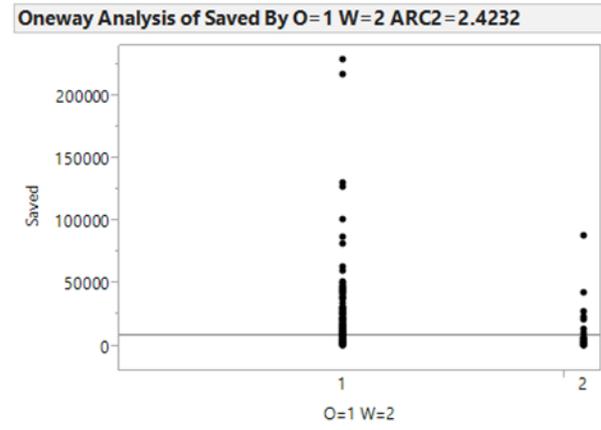
1-way Test, ChiSquare Approximation		
ChiSquare	DF	Prob>ChiSq
9.5544	1	0.0020*



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)						
Expected						
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0	
1	454	107242	109414	236.216	-3.095	
2	27	8679.00	6507.00	321.444	3.095	

2-Sample Test, Normal Approximation		
S	Z	Prob> Z
8679	3.09469	0.0020*

1-way Test, ChiSquare Approximation		
ChiSquare	DF	Prob>ChiSq
9.5815	1	0.0020*

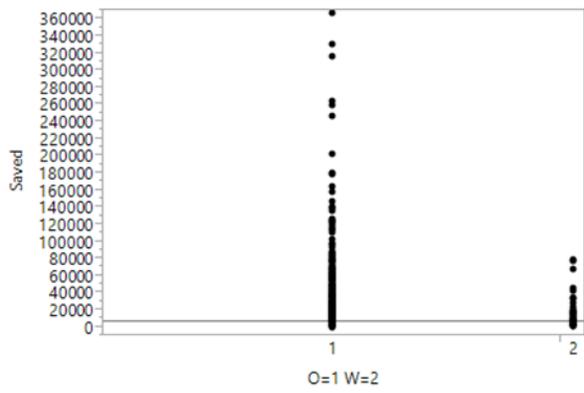


Wilcoxon / Kruskal-Wallis Tests (Rank Sums)						
Expected						
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0	
1	516	146669	144222	284.242	2.435	
2	42	9292.00	11739.0	221.238	-2.435	

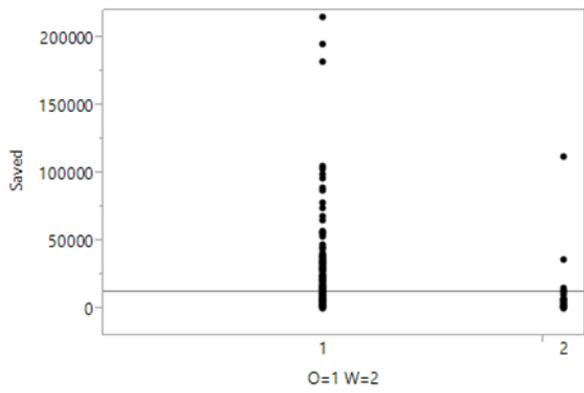
2-Sample Test, Normal Approximation		
S	Z	Prob> Z
9292	-2.43490	0.0149*

1-way Test, ChiSquare Approximation		
ChiSquare	DF	Prob>ChiSq
5.9311	1	0.0149*

Oneway Analysis of Saved By O=1 W=2 ARC2=2.7142



Oneway Analysis of Saved By O=1 W=2 ARC2=2.8121



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Expected		Score Mean	(Mean-Mean0)/Std0
		Score Sum	Score		
1	5885	1.84e+7	1.82e+7	3119.44	4.317
2	308	821844	953876	2668.32	-4.317

2-Sample Test, Normal Approximation

S	Z	Prob> Z
821844	-4.31652	<.0001*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
18.6325	1	<.0001*

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Expected		Score Mean	(Mean-Mean0)/Std0
		Score Sum	Score		
1	394	88240.5	85301.0	223.961	3.999
2	38	5287.50	8227.00	139.145	-3.999

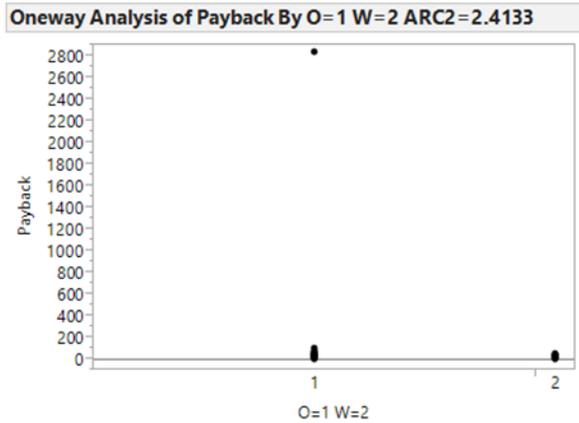
2-Sample Test, Normal Approximation

S	Z	Prob> Z
5287.5	-3.99859	<.0001*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
15.9941	1	<.0001*

Wood vs Non-wood Payback, Wilcoxon Results



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

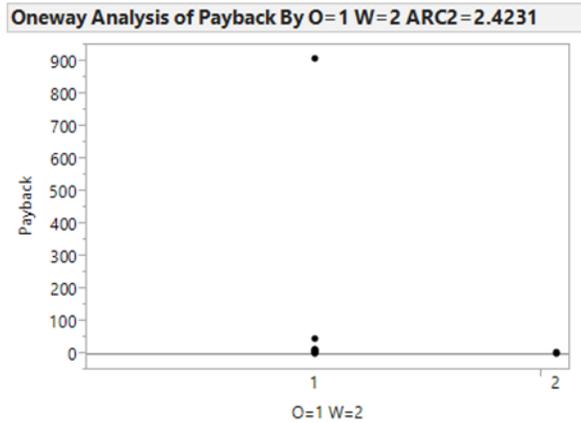
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0
1	2833	4321105	4374152	1525.28	-3.898
2	254	445223	392176	1752.85	3.898

2-Sample Test, Normal Approximation

S	Z	Prob> Z
445223	3.89825	<.0001*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
15.1966	1	<.0001*



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

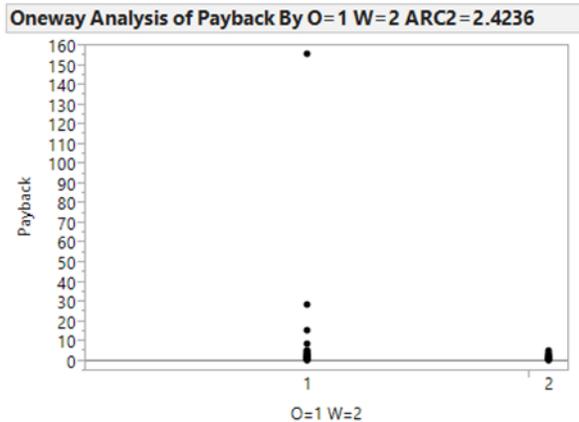
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0
1	1843	1790606	1803376	971.57	-2.237
2	113	123340	110571	1091.50	2.237

2-Sample Test, Normal Approximation

S	Z	Prob> Z
123340	2.23729	0.0253*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
5.0058	1	0.0253*



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

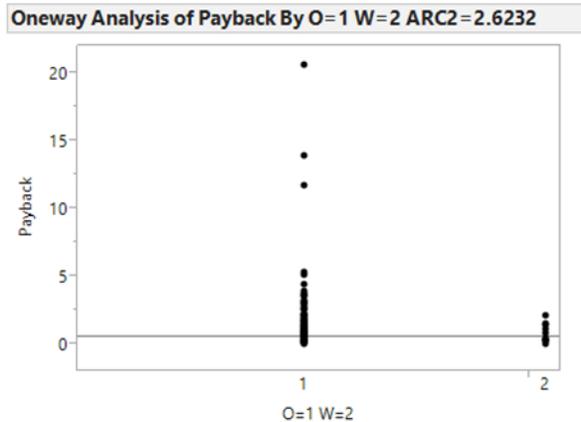
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0
1	5443	1.59e+7	1.61e+7	2924.59	-6.221
2	488	1672805	1447408	3427.88	6.221

2-Sample Test, Normal Approximation

S	Z	Prob> Z
1672805	6.22128	<.0001*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
38.7044	1	<.0001*



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0
1	468	119157	117234	254.609	2.475
2	32	6093.00	8016.00	190.406	-2.475

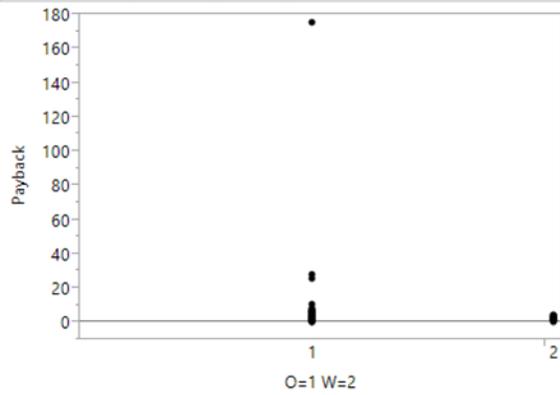
2-Sample Test, Normal Approximation

S	Z	Prob> Z
6093	-2.47455	0.0133*

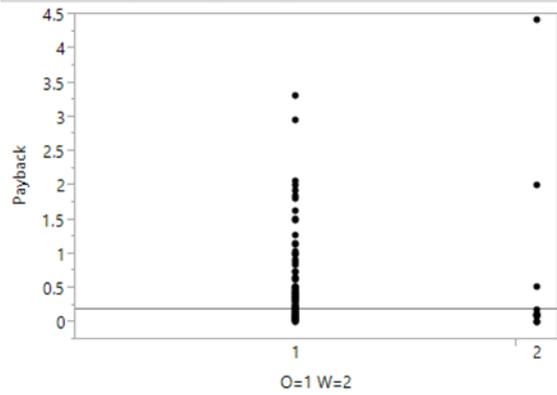
1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.1266	1	0.0133*

Oneway Analysis of Payback By O=1 W=2 ARC2=2.7135



Oneway Analysis of Payback By O=1 W=2 ARC2=2.8121



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		
			Score	Score Mean	(Mean-Mean0)/Std0
1	1244	796259	804868	640.079	-3.358
2	49	40312.5	31703.0	822.704	3.358

2-Sample Test, Normal Approximation

S	Z	Prob> Z
40312.5	3.35790	0.0008*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
11.2768	1	0.0008*

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		
			Score	Score Mean	(Mean-Mean0)/Std0
1	394	87231.5	85301.0	221.400	2.681
2	38	6296.50	8227.00	165.697	-2.681

2-Sample Test, Normal Approximation

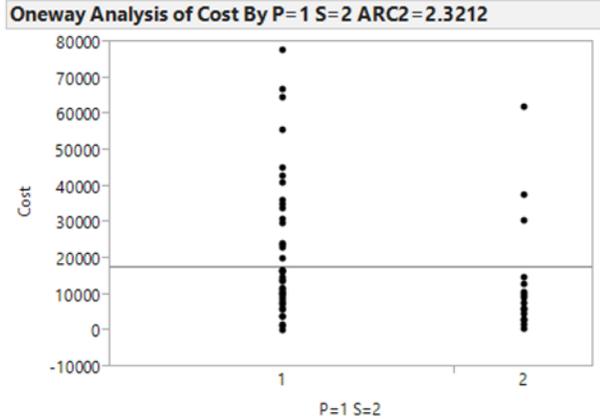
S	Z	Prob> Z
6296.5	-2.68141	0.0073*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
7.1937	1	0.0073*

APPENDIX H

Primary vs Secondary Cost, Wilcoxon Results



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

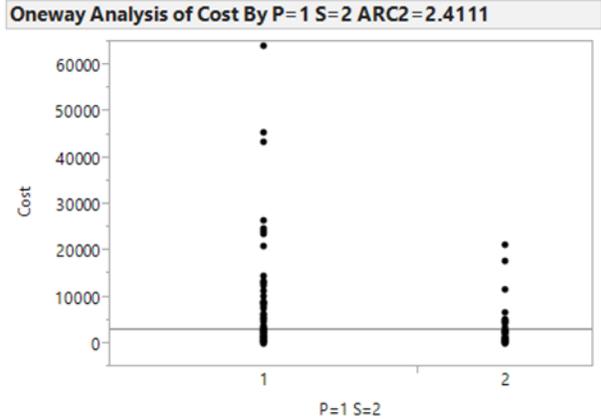
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
1	47	1727.00	1574.50	36.7447	2.153
2	19	484.000	636.500	25.4737	-2.153

2-Sample Test, Normal Approximation

S	Z	Prob> Z
484	-2.15266	0.0313*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
4.6645	1	0.0308*



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

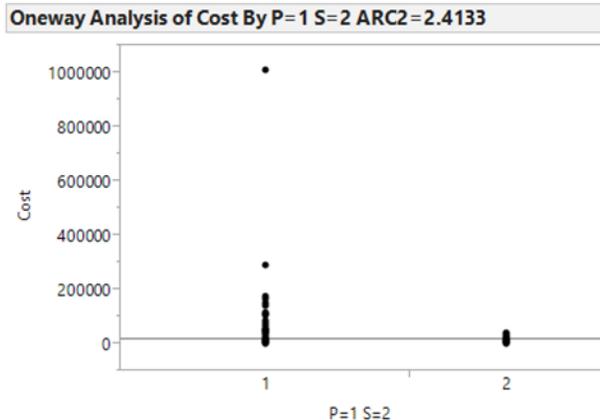
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
1	130	14204.0	13325.0	109.262	2.278
2	74	6706.00	7585.00	90.622	-2.278

2-Sample Test, Normal Approximation

S	Z	Prob> Z
6706	-2.27762	0.0227*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
5.1935	1	0.0227*



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

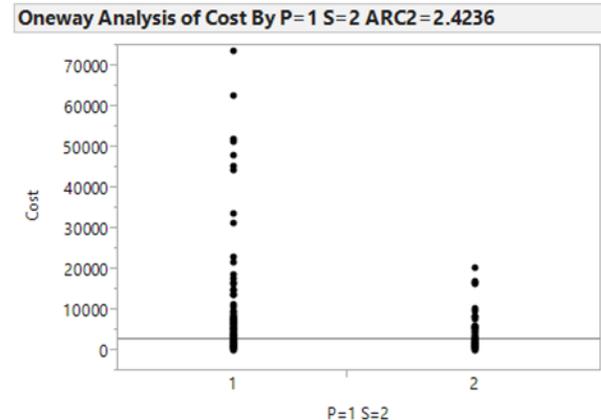
Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
1	153	21739.0	19507.5	142.085	3.893
2	101	10646.0	12877.5	105.406	-3.893

2-Sample Test, Normal Approximation

S	Z	Prob> Z
10646	-3.89327	<.0001*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
15.1643	1	<.0001*



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
1	232	63092.5	56724.0	271.950	4.094
2	256	56223.5	62592.0	219.623	-4.094

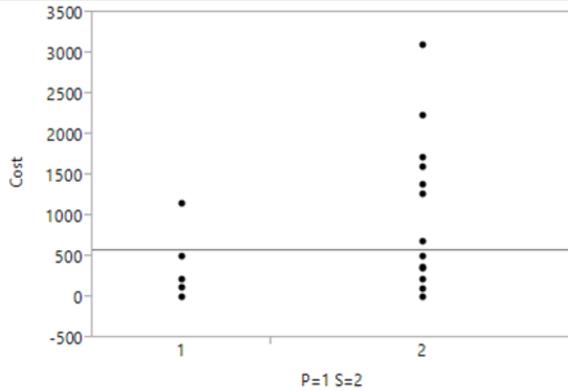
2-Sample Test, Normal Approximation

S	Z	Prob> Z
63092.5	4.09351	<.0001*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
16.7595	1	<.0001*

Oneway Analysis of Cost By P=1 S=2 ARC2=2.4314



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		(Mean-Mean0)/Std0
			Score	Score Mean	
1	10	97.000	140.000	9.7000	-2.190
2	17	281.000	238.000	16.5294	2.190

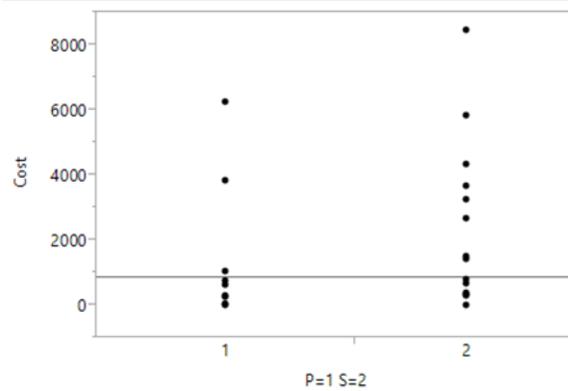
2-Sample Test, Normal Approximation

S	Z	Prob> Z
97	-2.18977	0.0285*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
4.9086	1	0.0267*

Oneway Analysis of Cost By P=1 S=2 ARC2=2.6212



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		(Mean-Mean0)/Std0
			Score	Score Mean	
1	30	704.000	855.000	23.4667	-2.664
2	26	892.000	741.000	34.3077	2.664

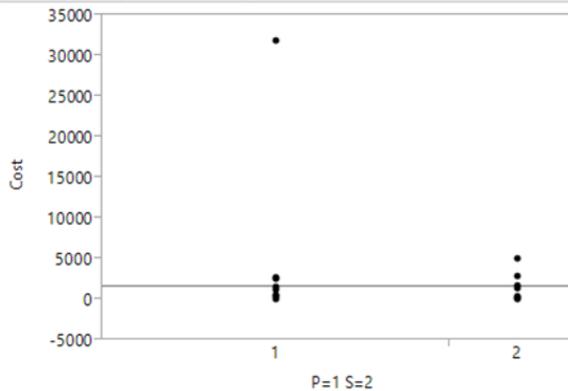
2-Sample Test, Normal Approximation

S	Z	Prob> Z
892	2.66438	0.0077*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
7.1462	1	0.0075*

Oneway Analysis of Cost By P=1 S=2 ARC2=2.6232



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		(Mean-Mean0)/Std0
			Score	Score Mean	
1	23	335.000	379.500	14.5652	-2.034
2	9	193.000	148.500	21.4444	2.034

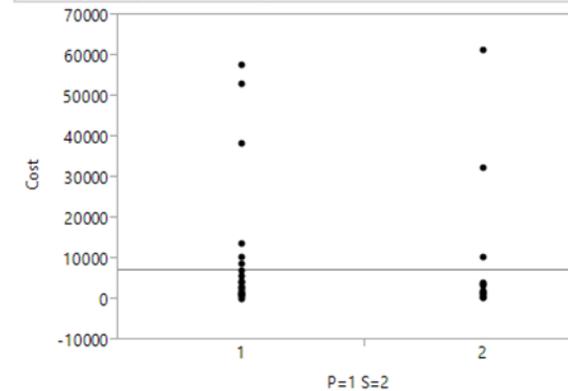
2-Sample Test, Normal Approximation

S	Z	Prob> Z
193	2.03358	0.0420*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
4.2300	1	0.0397*

Oneway Analysis of Cost By P=1 S=2 ARC2=2.7135



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		(Mean-Mean0)/Std0
			Score	Score Mean	
1	25	725.000	625.000	29.0000	1.990
2	24	500.000	600.000	20.8333	-1.990

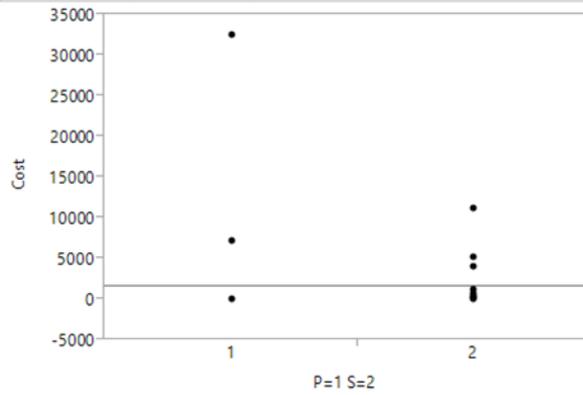
2-Sample Test, Normal Approximation

S	Z	Prob> Z
500	-1.99000	0.0466*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
4.0000	1	0.0455*

Oneway Analysis of Cost By P=1 S=2 ARC2=2.8121



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		
			Score	Score Mean	(Mean-Mean0)/Std0
1	20	290.000	390.000	14.5000	-3.297
2	18	451.000	351.000	25.0556	3.297

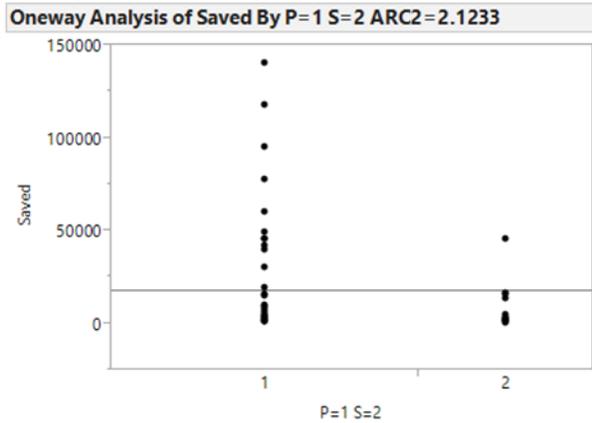
2-Sample Test, Normal Approximation

S	Z	Prob> Z
451	3.29680	0.0010*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
10.9784	1	0.0009*

Primary vs Secondary Saved, Wilcoxon Results



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

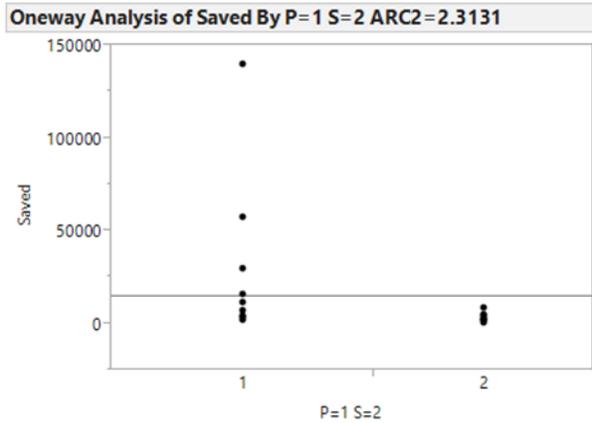
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0
1	35	1121.00	980.000	32.0286	2.458
2	20	419.000	560.000	20.9500	-2.458

2-Sample Test, Normal Approximation

S	Z	Prob> Z
419	-2.45824	0.0140*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
6.0860	1	0.0136*



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

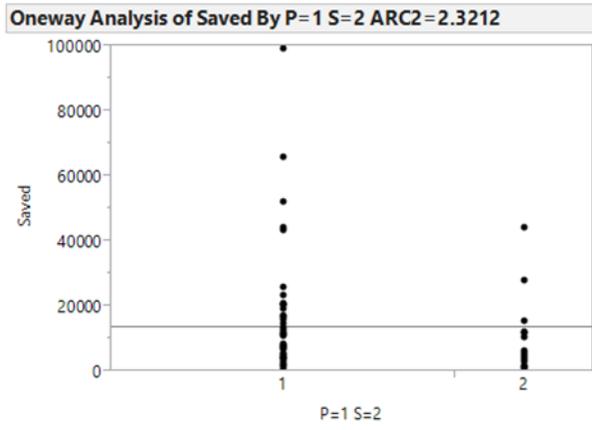
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0
1	12	168.000	138.000	14.0000	1.945
2	10	85.000	115.000	8.5000	-1.945

2-Sample Test, Normal Approximation

S	Z	Prob> Z
85	-1.94517	0.0518

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
3.9130	1	0.0479*



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

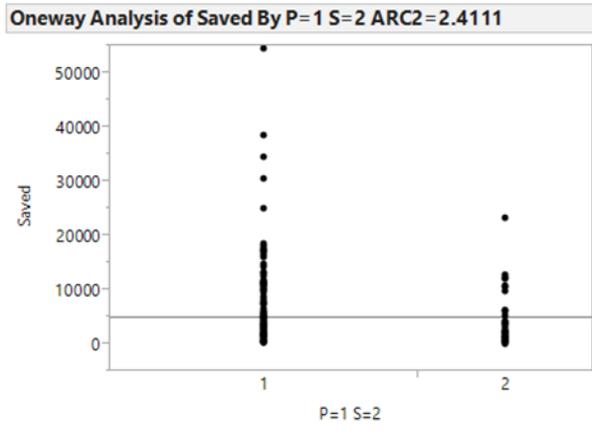
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0
1	47	1747.00	1574.50	37.1702	2.436
2	19	464.000	636.500	24.4211	-2.436

2-Sample Test, Normal Approximation

S	Z	Prob> Z
464	-2.43588	0.0149*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
5.9681	1	0.0146*



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0
1	130	15452.0	13325.0	118.862	5.246
2	74	5458.00	7585.00	73.757	-5.246

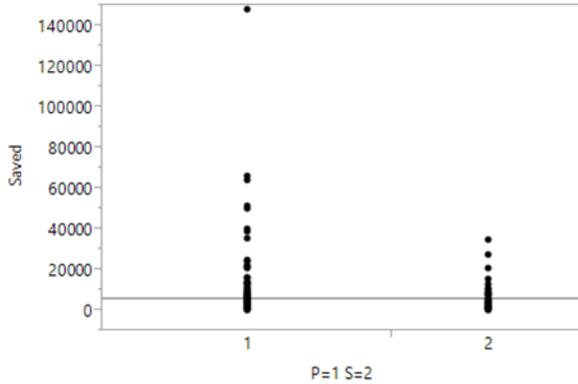
2-Sample Test, Normal Approximation

S	Z	Prob> Z
5458	-5.24556	<.0001*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
27.5288	1	<.0001*

Oneway Analysis of Saved By P=1 S=2 ARC2=2.4133



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		
			Score	Score Mean	(Mean-Mean0)/Std0
1	153	21583.5	19507.5	141.069	3.622
2	101	10801.5	12877.5	106.946	-3.622

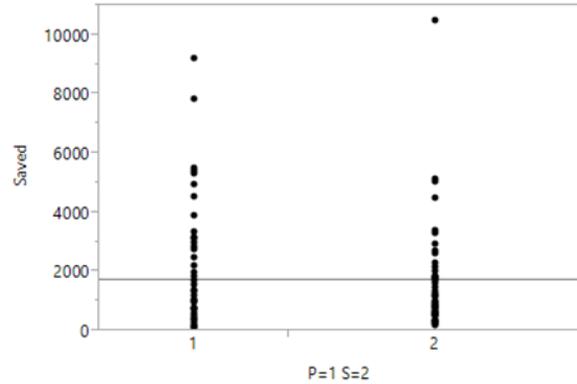
2-Sample Test, Normal Approximation

S	Z	Prob> Z
10801.5	-3.62190	0.0003*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
13.1245	1	0.0003*

Oneway Analysis of Saved By P=1 S=2 ARC2=2.4221



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		
			Score	Score Mean	(Mean-Mean0)/Std0
1	42	2641.00	2268.00	62.8810	2.376
2	65	3137.00	3510.00	48.2615	-2.376

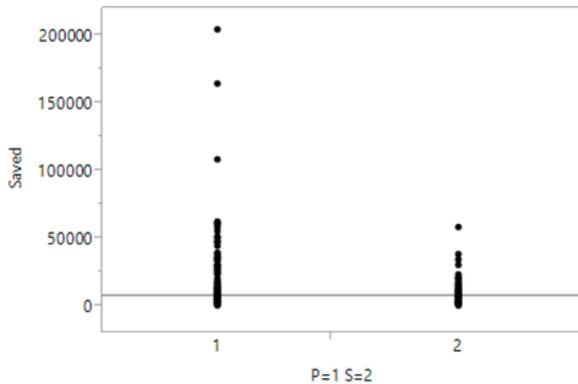
2-Sample Test, Normal Approximation

S	Z	Prob> Z
2641	2.37642	0.0175*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
5.6626	1	0.0173*

Oneway Analysis of Saved By P=1 S=2 ARC2=2.4236



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		
			Score	Score Mean	(Mean-Mean0)/Std0
1	232	63341.5	56724.0	273.024	4.253
2	256	55974.5	62592.0	218.650	-4.253

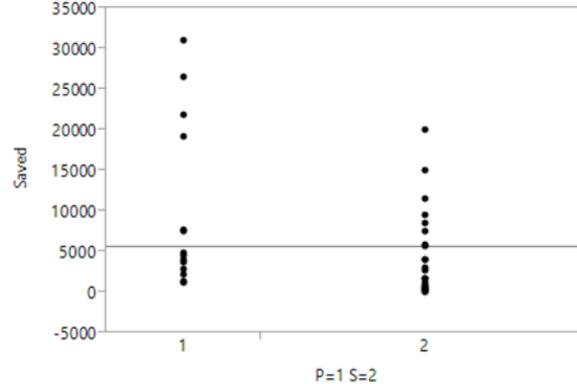
2-Sample Test, Normal Approximation

S	Z	Prob> Z
63341.5	4.25337	<.0001*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
18.0939	1	<.0001*

Oneway Analysis of Saved By P=1 S=2 ARC2=2.6218



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		
			Score	Score Mean	(Mean-Mean0)/Std0
1	15	458.000	360.000	30.5333	2.225
2	32	670.000	768.000	20.9375	-2.225

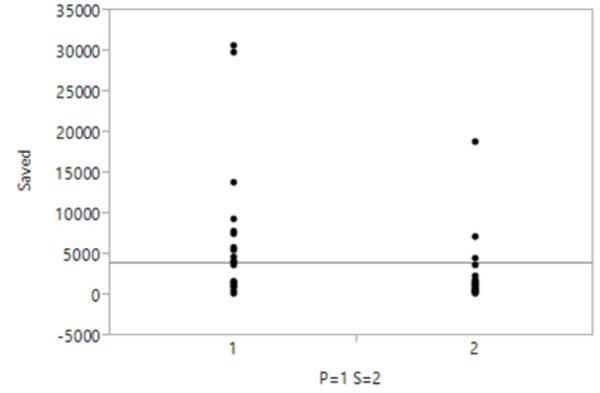
2-Sample Test, Normal Approximation

S	Z	Prob> Z
458	2.22512	0.0261*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
5.0021	1	0.0253*

Oneway Analysis of Saved By P=1 S=2 ARC2=2.7135



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		
			Score	Score Mean	(Mean-Mean0)/Std0
1	25	741.000	625.000	29.6400	2.310
2	24	484.000	600.000	20.1667	-2.310

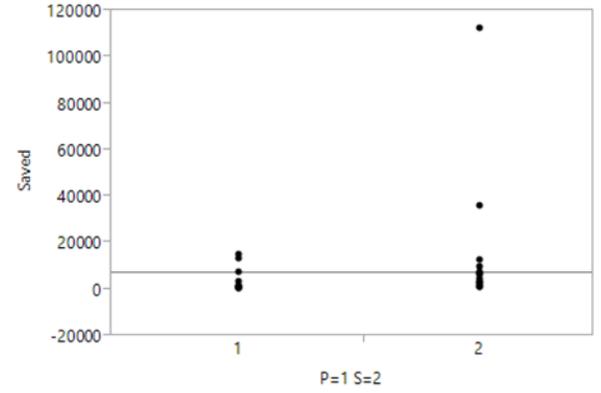
2-Sample Test, Normal Approximation

S	Z	Prob> Z
484	-2.31000	0.0209*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
5.3824	1	0.0203*

Oneway Analysis of Saved By P=1 S=2 ARC2=2.8121



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		
			Score	Score Mean	(Mean-Mean0)/Std0
1	20	281.000	390.000	14.0500	-3.172
2	18	460.000	351.000	25.5556	3.172

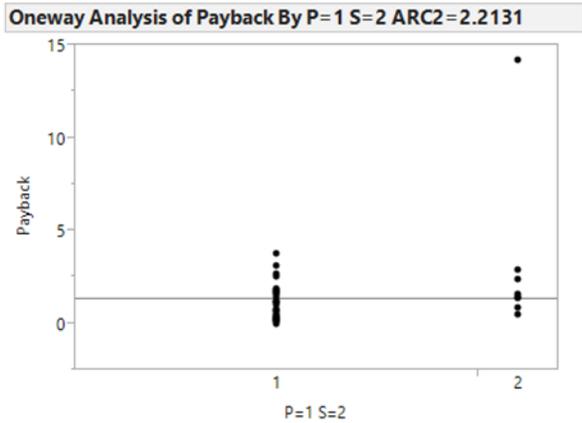
2-Sample Test, Normal Approximation

S	Z	Prob> Z
460	3.17203	0.0015*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
10.1547	1	0.0014*

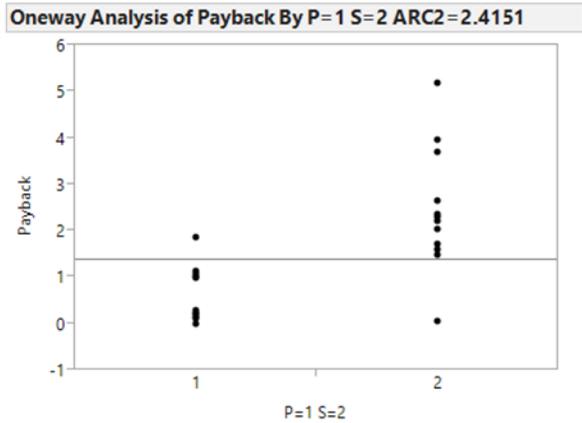
Primary vs Secondary Payback, Wilcoxon Results



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)					
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0
1	40	896.000	980.000	22.4000	-2.310
2	8	280.000	196.000	35.0000	2.310

2-Sample Test, Normal Approximation		
S	Z	Prob> Z
280	2.30996	0.0209*

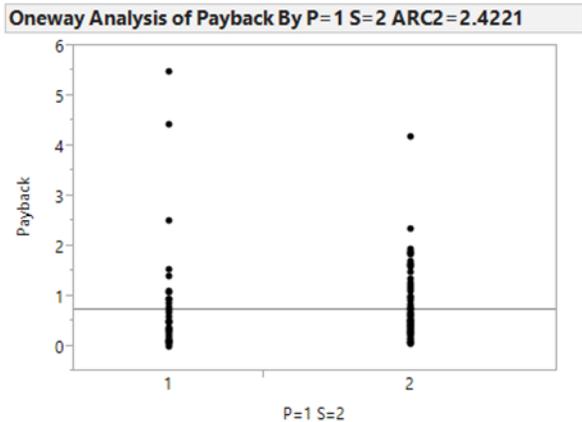
1-way Test, ChiSquare Approximation		
ChiSquare	DF	Prob>ChiSq
5.4000	1	0.0201*



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)					
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0
1	13	118.000	175.500	9.0769	-2.923
2	13	233.000	175.500	17.9231	2.923

2-Sample Test, Normal Approximation		
S	Z	Prob> Z
233	2.92308	0.0035*

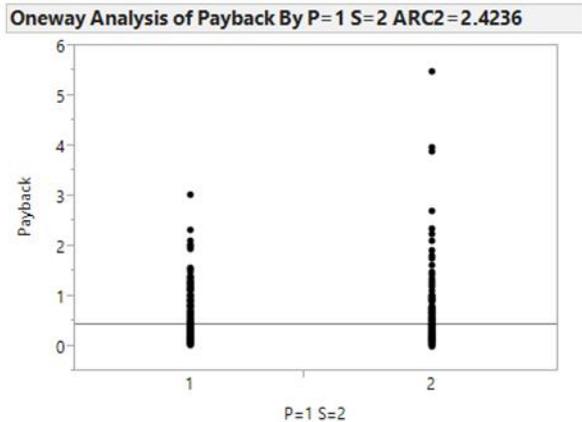
1-way Test, ChiSquare Approximation		
ChiSquare	DF	Prob>ChiSq
8.6949	1	0.0032*



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)					
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0
1	42	1914.00	2268.00	45.5714	-2.255
2	65	3864.00	3510.00	59.4462	2.255

2-Sample Test, Normal Approximation		
S	Z	Prob> Z
1914	-2.25521	0.0241*

1-way Test, ChiSquare Approximation		
ChiSquare	DF	Prob>ChiSq
5.1004	1	0.0239*

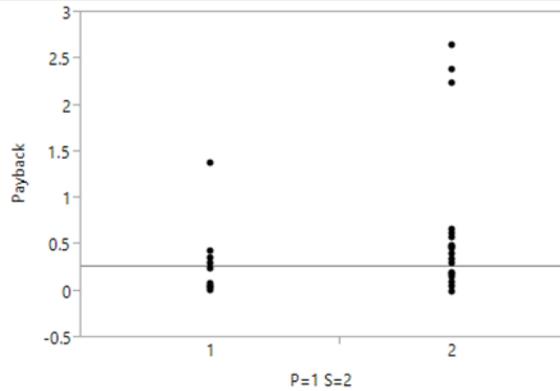


Wilcoxon / Kruskal-Wallis Tests (Rank Sums)					
Level	Count	Score Sum	Score	Score Mean	(Mean-Mean0)/Std0
1	232	59824.5	56724.0	257.864	1.993
2	256	59491.5	62592.0	232.389	-1.993

2-Sample Test, Normal Approximation		
S	Z	Prob> Z
59824.5	1.99277	0.0463*

1-way Test, ChiSquare Approximation		
ChiSquare	DF	Prob>ChiSq
3.9724	1	0.0463*

Oneway Analysis of Payback By P=1 S=2 ARC2=2.6212



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		
			Score	Score Mean	(Mean-Mean0)/Std0
1	30	694.000	855.000	23.1333	-2.841
2	26	902.000	741.000	34.6923	2.841

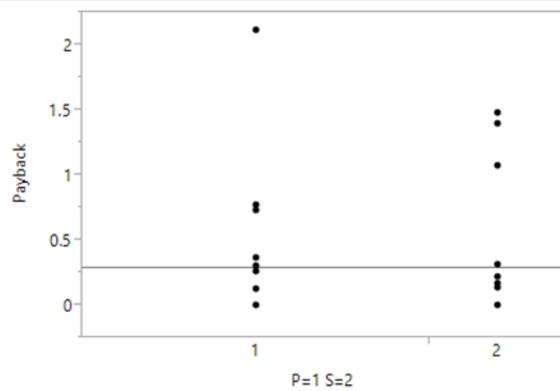
2-Sample Test, Normal Approximation

S	Z	Prob> Z
902	2.84130	0.0045*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
8.1234	1	0.0044*

Oneway Analysis of Payback By P=1 S=2 ARC2=2.6232



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		
			Score	Score Mean	(Mean-Mean0)/Std0
1	23	331.000	379.500	14.3913	-2.218
2	9	197.000	148.500	21.8889	2.218

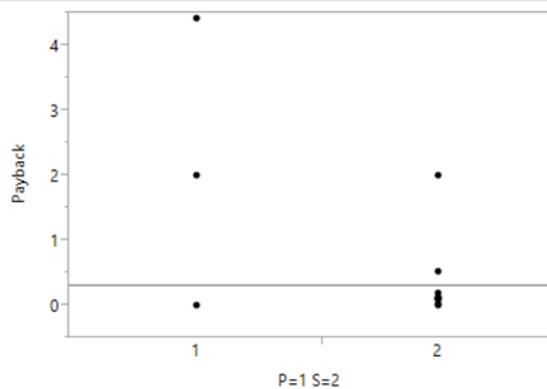
2-Sample Test, Normal Approximation

S	Z	Prob> Z
197	2.21845	0.0265*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
5.0246	1	0.0250*

Oneway Analysis of Payback By P=1 S=2 ARC2=2.8121



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected		
			Score	Score Mean	(Mean-Mean0)/Std0
1	20	290.000	390.000	14.5000	-3.298
2	18	451.000	351.000	25.0556	3.298

2-Sample Test, Normal Approximation

S	Z	Prob> Z
451	3.29772	0.0010*

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
10.9845	1	0.0009*