

2006

Lean manufacturers transcendence to green manufacturing: Correlating the diffusion of lean and green manufacturing systems

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Lean Manufacturers Transcendence to Green Manufacturing:
Correlating the Diffusion of Lean and Green Manufacturing Systems

by

Gary G. Bergmiller

A dissertation submitted in partial fulfillment
of the requirements for the degree of
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Date of Approval:
October 9, 2006

Keywords: environmentally conscious manufacturing, continuous improvement,
waste minimization, sustainable development, Shingo Prize

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Dedication

*To my loving wife Dianna and our wonderful children
Brigit and Leo. Through this long journey your
support was unwavering and I could not have
accomplished it without you by my side.*

Acknowledgements

This dissertation is the culmination of years of effort and support by the wonderful group of friends I have gained along this awesome journey. A dissertation is like climbing a great mountain from whose summit you see so many other mountains, and you are equipped with the knowledge and confidence to climb them all.

I was privileged to have such a supportive research committee: To Paul McCright who prepared and guided me from the very beginning of this journey, offered encouragement at every valley, celebrated every peak along the way, and personally assured the quality of this paper. To Ali Yalcin who stepped-up when a co-chair was needed and offered structure and expediency to get me through this process most efficiently. To Sheldon Busansky who played a brilliant “devils advocate” to assure the study was strong and achievable. To Michael Brannick who guided me through the challenging terrain of statistical analysis by offering many hours of consultation. To Glenn Besterfield who always had thought provoking questions to make me think beyond the confinements of my study. To the late Richard Stessel who instilled in me the responsibility and urgency to integrate environmental issues into Industrial Engineering research.

To the Shingo Prize team at Utah State University who offered incredible support and access to their information and industrial partners. Their support assured a high level of strength and credibility, otherwise unachievable. I personally want to thank Ross Robson for his vision and commitment to further Lean and Green manufacturing research.

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ABSTRACT

Scientific evidence of human impact on the natural environment, such as global warming, continues to mount. Green manufacturing systems that focus on minimizing environmental impact of manufacturing processes and products are ever more important to our sustainable future. Green manufacturing systems are slow to gain acceptance as manufacturers are focused on implementing Lean manufacturing systems, generally considered the most competitive manufacturing systems in the world. In recent years, researchers and the US Environmental Protection Agency (EPA) have sought to “build a bridge” between Lean and Green manufacturing systems, in hopes that the rapid expanse of Lean can serve as a catalyst to the implementation of Green manufacturing systems.

This study contributes to this growing body of knowledge by determining if leading Lean manufacturers are transcending beyond the traditional limits of Lean and implementing Green manufacturing systems as part of their overall

waste reduction strategy. In this work Lean manufacturing plants that have been evaluated by a panel of experts from the Shingo Prize for Excellence in Manufacturing are surveyed on the diffusion of Green manufacturing system practices throughout their operation. A full system correlation analysis is performed utilizing forty-eight measures of Lean and Green manufacturing systems under the categories of management system, waste reducing techniques, and results.

Data analysis indicates that known Lean manufacturers are significantly Greener than the general population of manufacturers in twenty-five of twenty-six measures of Green manufacturing. Lean manufacturers who implement Green manufacturing systems have the strongest results in both Lean and Green result areas, particularly cost reduction, indicating synergy between Lean and Green manufacturing systems. Manufacturing plants that choose to vertically integrate versus horizontally integrate their Lean systems transcend to Green manufacturing. Mexican plants in the study practice significantly higher levels of material resource efficiency and are more inclined to develop industrial partnerships to resolve environmental issues. The study also identifies a critical need for integrating Lean and Green management systems to drive synergistic waste reducing techniques throughout the operation. An integrated Lean and Green manufacturing system model, dubbed “Zero Waste Manufacturing”, is proposed as a solution for economically and environmentally sustainable manufacturing.

Chapter One

Introduction

“The idea that our natural resources were inexhaustible still obtained, and there was as yet no real knowledge of their extent and condition. The relation of the conservation of natural resources to the problems of National welfare and National efficiency had not yet dawned on the public mind.”

Theodore Roosevelt (1858–1919)

Background

During the end of the twentieth century and into the twenty-first century two types of manufacturing systems that emphasize waste minimization have gained in popularity. They are “Lean” manufacturing systems that reduce waste defined as non-value added activity, and “Green” manufacturing systems that reduce waste defined as having adverse environmental impact. Green manufacturing is an essential part of sustainable development: Development balanced with the earth’s capacity to supply natural resources and process wastes.

However, the rate at which Green manufacturing systems are being implemented is not keeping pace with the rapid global expanse of the manufacturing industry, and thus over time we are becoming less “sustainable”. Lean manufacturing is rapidly spreading around the world as the premier alternative to the outdated mass production model, for producing quality product, at the lowest cost and shortest time. If Green manufacturing can be integrated with Lean manufacturing, such that Lean serves as a catalyst to Green manufacturing implementation, economically and environmentally sustainable manufacturing could be realized.

Several research efforts summarized in the literature review indicate how Lean companies show significant environmental improvements by being more resource and energy efficient. Some of the studies also show how both systems share many of the same best practices to reduce their respective wastes. Yet, the consensus view is that these two systems tend to operate independently, administered by distinctly different personnel, even within the same manufacturing plant. The United States Environmental Protection Agency (EPA) very eloquently describes the division of environmental personnel focused on Green manufacturing system implementation and operations personnel focused on Lean manufacturing system implementation as “living in parallel universes of waste reduction”. (EPA, 2003)

To date, there is little empirical evidence that Lean manufacturers transcend beyond the environmental bi-products of their Lean system and actually commit

themselves to a comprehensive Green manufacturing system, which leads to continuous environmental improvement. If it is true that Lean manufacturing serves as a catalyst to Green manufacturing system implementation, then this relationship could have a profound effect on the means by which Green manufacturing systems are promoted by agencies such as the EPA, which is currently supporting research on this topic. This research project intends to determine if Lean manufacturers transcend beyond the traditional limits of their Lean manufacturing system to include Green manufacturing system components in their overall strategy to reduce waste.

Relevance of Topic

The twentieth century reminded us that the earth is finite in both its ability to produce raw material and safely process waste. Greater legitimacy is given to global warming theories, emphasizing green house gas releases from industrial processes and their products as a major cause. The last decade of the second millennium was the warmest decade ever recorded, and the first decade of the new millennium is on track to also earn this dubious distinction. Global warming causes drought and rising sea levels that in time will flood densely populated coastal areas, such as Florida.

The past century also showed us how industrialization gone unchecked can pollute water and airways making the very elements of life toxic. We also saw substantial damage to the ozone layer, the thin film that protects all fauna and flora from the Sun's deadly ultraviolet radiation (National Geographic, 2004).

Biodiversity, the delicate balance of all living things, is also threatened as an estimated 10 to 100 species become extinct every day, due mostly to tropical rain forest deforestation for industrial purposes and population expansion. This species extinction rate was only matched by the end of the Cretaceous age that eliminated the dinosaurs (Meadows et al, 2004). Fortunately, the environmental legislation (i.e. Clean air and Clean water acts, and the global ban on CFCs) slowed the rate of environmental devastation. But it is a painful reminder of how mankind can, without even knowing it, cause major imbalances to earth's life sustaining systems.

Global human population, which took 600,000 years, from the Stone Age to 1900, to reach 1.6 Billion, reached 6 Billion in the year 2000 (Meadows et al, 2004) (U.S. Census, 2003). At the same time, per capita consumption and pollution levels are increasing as developing countries strive for the same standard of living as developed countries. Human population and the amount of waste humans generate are growing at unsustainable rates: beyond the earth's ability to support these activities. If something is not done to change the course of human development, the situation will only worsen. Although technology has greatly decreased the environmental impact of industry, the rate of consumption and production outpaces these innovations.

All of these environmental indicators lead to several stark realities summarized in the 2004 release of thirty-year update to the famous book Limits to Growth (Meadows, et al 2004). For thirty years researchers at MIT have been refining an

elaborate computer model of earth systems to monitor and predict when raw material “sources” and earth’s capacity for waste processing “sinks” are beyond the earth’s ability to replenish or sustain them. A brief synopsis of their findings follows:

- The human economy is now using many critical resources and producing wastes at rates that are not sustainable. Sources are being depleted. Sinks are filling up, in some cases, overflowing. Most throughput streams cannot be maintained over the long term even at their current flow rates, much less increased. We expect many of the will reach their peaks and then decline in this century.
- These high rates of throughput are not necessary. Technical, distributional, and institutional changes could reduce them greatly while sustaining and even improving the average quality of life of the world’s people.
- The human burden on the natural environment is already above sustainable levels, and it cannot be maintained for more than a generation or two. As a consequence, there are already apparent many negative impacts on human health and the economy.
- The true costs of materials are increasing.

(Meadows et al, 2004)

A global solution is required that allows for progress, while not degrading the overall quality of the environment. Many believe that ‘sustainable development’ is the only reasonable solution for humans to achieve balance with nature. The simplest definition of sustainable development is ‘...development that meets the needs of the present without compromising the ability for future generations to meet their own needs.’ (WCED, 1991) This does not imply absolute limits to growth, rather, that consumption of natural resources and the emission of wastes do not exceed the earth’s ability to support these activities. The following quote from Meadows captures the distinction between development and growth:

“... To ‘grow’ means to increase in size by the assimilation or accretion of materials. To ‘develop’ means to expand or realize the potentials of; to bring to a fuller, greater, or better state. When something grows it gets quantitatively

bigger, when it develops it gets qualitatively better, or at least different. Quantitative growth and qualitative improvement follow different laws. Our planet develops over time without growing. Our economy, a subsystem of the finite and non-growing earth, must eventually adapt to a similar pattern of development.” (Meadows et. al., 2004)

Sustainable development theorists break global environmental problems into two major socio-economic categories, population growth and unsustainable resource consumption. Population is growing exponentially, mostly as a result of developing nation's birth rates. Industrial nation's per capita natural resource consumption is much greater than that of developing nations. “Americans pollute 30 to 100 times more than the average third world citizen”(Prokop, 1993). These combined behaviors of industrial and developing nations are unsustainable.

Some sociologists believe that families in developing nations compensate for high infant and child mortality rates by having large families. Lack of birth control also increases unwanted pregnancies in developing nations. There are other religious and social paradigms that lead to high birth rate. Regardless of the root cause, over-population causes people in developing nations to strip their natural landscapes so they can expand their villages, grow additional crops, and raise cattle (typically for export to industrial nations) to support their families.

Deforestation causes precious topsoil to be washed into the waterways making the land and water incapable of regeneration. (Meadows et al, 2004)

History shows that as a country becomes industrialized population growth slows to zero. The sociological reasoning for this phenomenon is that industrialization improves the standard of living, which reduces infant mortality rates. Child health security leads families to limit their size, to a point where zero net population

growth occurs. Zero population growth means that natural habitats are not destroyed by human migration. Although industrial nations experience little population growth, their per capita natural resource consumption is the greatest in the world. Manufacturing practices, waste disposal methods, and consumer behavior together have caused industrial nations to consume and degrade natural resources at an unsustainable rate. Here in lies the paradox: If industrialization is the proven way to stem population growth, yet the source of most environmental waste, how can industrialization occur in a sustainable manner?

One of the essential components of a sustainable society is Green manufacturing, manufacturing that assures sustainability in resource extraction, material processing, product use and disposal. Open-ended processes such as resource extraction and waste disposal are replaced with a “closed loop” industrial system that emphasizes waste reduction, reuse and recycling. Green manufacturing could solve the unsustainable behaviors of both developing and industrialized countries. Industrialized countries could maintain the same standard of living with less adverse impact on the environment. Developing countries could industrialize without devastating their natural resources. This would increase their economic and health security, eventually leading to zero population growth.

Yet, given all of the importance of Green manufacturing to the global environmental problem, many companies are still skeptical about the business

benefits of Green manufacturing. Even though many Green manufacturing success stories have proven this point, it seems most manufacturing managers still see environmental waste minimization not as a competitive opportunity but as a necessary evil, simply to avoid EPA sanctions and future liability. Burt Hamner, a major advocate of environmental waste minimization, graphically depicted a sorry state of affairs by indicating how industry was littered with the bodies of unemployed pollution prevention experts who tried to sell waste minimization initiatives on environmental merits rather than on the basis of resource efficiency and cost reduction. (Hamner, 2002).

However, most companies readily see the business benefits of Lean manufacturing. Any efforts to link Green manufacturing with Lean manufacturing can serve as a catalyst to promote Green manufacturing and the resulting environmentally sustainable benefits. If it is true that Lean and Green systems are complementary and even synergistic, the debate over whether being Green is good for business or not could end. Clearly this subject is worthy of complete exploration.

In recent years, the EPA has funded research that shows how manufacturers implementing Lean are having significant Green results (e.g. less energy, less scrap, less floor space per unit output). However, the EPA is quick to note that Lean strategies do not target environmental wastes, rather the traditional 7 wastes associated with Lean (Defects, Over-production, Transport, Waiting, Inventory, Motion, excess-Processing – DOTWIMP) They are eager to promote

research to “build a bridge” between Lean and Green to help integrate true Green waste reducing techniques. (EPA, 2003).

One strong realization the EPA made in its recent study is that Lean companies develop a “waste reduction culture” that is essential to the company embracing Lean or Green manufacturing systems. They find that Lean companies have already built waste reducing infrastructure that puts them well on their way to building a Green manufacturing system. If Lean manufacturing serves as a catalyst to Green manufacturing, then in addition to the productivity, quality, and cycle time improvements realized by the manufacturer, society benefits from its improved environmental performance: a win-win scenario. (EPA, 2003).

Purpose of Study

This dissertation builds upon recent research regarding the relationship between Lean and Green manufacturing systems. An empirical study of North America’s leading Lean manufacturers is conducted to determine if there is in fact a direct correlation between the level of diffusion of the Lean manufacturing system and the level of diffusion of the Green manufacturing system. The study performed on a set of known Lean manufacturers, recognized by experts from the Shingo Prize for Excellence in Manufacturing.

This dissertation will advance the Lean and Green manufacturing body of knowledge by determining if Lean manufacturing plants have expanded their systemic approach to waste reduction to include Green waste reduction. In other

words, do Lean manufacturers transcend beyond the environmentally beneficial byproducts of their Lean implementation to embrace a systemic approach to environmental waste reduction, akin to their systemic approach to reducing wastes associated with their Lean manufacturing system? The research question, put more succinctly is: *Do Lean manufacturers transcend to Green manufacturing?*

The unique contribution this dissertation makes is that it answers the research question from a full manufacturing systems perspective, on a population of leading Lean manufacturers. For purposes of this dissertation, a manufacturing system is defined as a collection of best practices that together achieve the objectives of that manufacturing system, to include but not limited to, management systems (i.e. policies and procedures), waste reducing techniques (i.e. actual process changes), and measurable results.

For comparative purposes, this study classifies both Lean and Green manufacturing system components into the same three main categories: Management systems, Waste reducing techniques, and Results. The management system defines the policies and procedures that create the environment/culture that commits the organization toward waste reduction, respective to each manufacturing system. Waste reducing techniques are the specific process (both business and production process) practices associated with each manufacturing system that result in waste reduction, respective to each

manufacturing system. Results are the measurable improvements to the stated objectives of each manufacturing system.

Comparative models developed in this study are based on leading scholarly research of Lean and Green manufacturing systems. It is important to develop models for each system that are robust enough to capture the complexities of each system, yet general enough to allow for meaningful correlation analysis between major factors of the two systems on a “apples to apples” basis.

Organization of Research

Chapter 1 presents an introduction to the research topic, its relevance, and purpose of this dissertation research.

Chapter 2 reviews the academic literature that is relevant to the topic of Lean and Green manufacturing systems. The first part of the Literature review offers a detailed review of Lean manufacturing system literature to provide in-depth understanding of Lean Philosophy and system components. This section is followed by analogous review of Green manufacturing system literature. The last section of the literature review is dedicated to previous research on the relationships between Lean and Green manufacturing systems that preceded this dissertation study.

Chapter 3 synthesizes previous Lean and Green manufacturing studies to build a foundation of this dissertation study. An evolutionary theory of Lean and Green systems is described to identify the research gap this study intends to fill.

Leading models of Lean and Green manufacturing systems are reviewed for application in the study's comparative research model. The chapter concludes with the statement of hypotheses this study sets out to prove.

Chapter 4 describes the research methodology. This entails the description of the independent, dependent and control variables, development and validation of research instruments, survey administration and data collection, and the selection of tools for statistical analysis.

Chapter 5 presents the results of this study along with the statistical reasoning behind these outcomes. Lean and Green manufacturing models are held up for statistical verification, main hypotheses are tested, and results of a full correlation and multi-variant regression analysis are described in detail.

Chapter 6 contains a discussion and interpretation of the results presented in Chapter 5 to give meaning to the statistical findings.

Chapter 7 presents the conclusions and contributions this study will make to both theory building and practice. It contains an overview, including the limitations of this study, directions for further research and a brief summary of what was learned from this study.

Chapter Two

Literature Review

Introduction

The literature review will begin with a historical background of Lean and Green manufacturing systems in order to bring the reader up to date as to how these systems, and related research, evolved over time. Following the background section will be a section dedicated to the latest research on Lean manufacturing system models followed by a similar section for Green manufacturing systems. Both the Lean and Green sections will describe the wastes these individual systems target and the various system models used to reduce them. Finally, the literature review will summarize all of the studies found to date that explored Lean and Green system correlation. This will prepare the reader for chapter three, where the literature review is synthesized to form the research model for this study.

Background

Early attempts to reduce the environmental impact of manufacturing processes had a negative relationship with productivity, and cost. Christiansen and Haveman (1981), Barbera and McConnell (1990) found that pollution abatement increased operating cost and/or reduction in plant productivity. The reason for

this negative relationship is that pollution abatement was addressed at the end-of-the-pipe. Environmental solutions were costly add-ons to existing processes and even restricted process output. Not only did these solutions restrict the manufacturing process, they were also ineffective in eliminating the targeted pollutants. End-of-pipe solutions simply transfer the media of the pollutant: e.g., a scrubber transfers air pollution into solid/hazardous waste¹. In other words, end-of-pipe solutions are a lose-lose scenario.

The 1980's and 1990's experienced a fundamental shift in how environmental issues were addressed. Rather than focus solely on end-of-pipe solutions, manufacturers started to address environmental waste at the source. In the late 1980's and early 1990's a movement began to disprove the adversarial relationship between environment and productivity and instead claim that "pollution prevention pays". The simple logic expressed in this movement is that pollution is essentially poorly used resources that cost money to dispose of and can lead to potential liability. In a study of companies in the Standard and Poor's 500 index, Hart and Ahuja (1996) found that efforts to reduce emissions (as measured from the Toxic Release Inventory (TRI), reported to the EPA) were significantly related to operating and financial performance. Several studies evolved that looked at the relationship between environmental performance and manufacturing performance. Morris (1997) who looked at the relationship between TRI emissions and Return on Assets (ROA) found that environmental performance reduced operating costs.

¹ It should be noted that transferring a waste from an airborne state to a solid waste may reduce the near term environmental impact of the pollutant.

One of the major proponents of this change in industrial thinking was the Office of Technology Assessment, who made it clear that pollution prevention and minimization of environmental waste at the source were the way of the future. (Hirschorn and Oldenburg, 1988; Roy, 1988; Office of Policy Planning and Evaluation; 1991, Byers, 1992). International interest in proactive environmental management systems that embody the principles of PP/WM led to the creation of ISO14000, an international Environmental Management System (EMS) standard, in the mid 1990's. All of these approaches to improving the environmental performance of companies are categorized under the subject of Green manufacturing, for purposes of this study.

During this same period in the twentieth century, several advanced manufacturing strategies were beginning to transform traditional approaches to quality and productivity. One of these was Lean manufacturing, a term coined by the MIT research team that studied the Japanese automotive manufacturing industry and compared it to other country's automotive manufacturing performance. The MIT study, embodied in the book, "*The Machine that Changed the World*" (Womack, 1990) proved that Lean manufacturers had superior productivity, quality, and responsiveness over traditional (mass production) manufacturers.

The term Lean reflected a philosophy that targeted waste in every facet of the manufacturing business, including suppliers and customers, design, human resources, management, etc. A survey by Osterman (1994) shows significant

adoption of Lean manufacturing techniques amongst US manufacturers.

MacDuffie (1995) identified performance gains as a result of implementing Lean manufacturing. Ichniowski (1993) found significant performance gains from a bundle of innovative manufacturing and work organization practices associated with the Lean system. Confronted with the undeniable benefits of Lean manufacturing, companies all over the world started jumping on the Lean manufacturing bandwagon during the 1990's and early 21st century.

Growing interest in both Lean and Green manufacturing systems led to natural curiosity about their potential relationship. The findings from an MIT research effort indicates a relationship between Lean manufacturing and innovative environmental practices (Maxwell et al, 2001). Wallace (1995) indicated that both radical technology innovation and continuous improvement (e.g. kaizen) created significant opportunities for pollution prevention. Researchers at the University of Michigan found that efforts to prevent pollution and reduce emissions had a positive effect on industrial performance (Hart et al, 1996).

Early studies on Lean and Green manufacturing systems and their potential relationship led to scholarly research and the creation of system models in the late 1990's and this work continues today. These studies are summarized in the literature review that follows. The literature review will first explore literature specialized to either Lean or Green manufacturing systems in order to gain a strong understanding of the components that comprise these systems. Secondly, the literature review will explore all of the studies found focused on the

Lean and Green relationship to understand the correlations found to date and the methodologies used to achieve these results. Synthesis of this literature review in Chapter three will identify the research gap and proposed actions to close that gap.

The literature review is based on research through leading journals and books on Lean and/or Green manufacturing. Articles were found through searches on a variety of scholarly engineering, industry and business databases. Books were typically found through searches on trade organization websites, publishing houses specific to topical areas, and recommended through Lean and Environmental listserv communication.

Lean Manufacturing Literature Review

Background

Manufacturers are rapidly transforming their manufacturing systems from traditional mass production to flexible lean systems. As early as 1994, Osterman found a significant rate of adoption of Lean manufacturing systems across a wide sample of U.S. business establishments. A more recent study found that 50% of US manufacturers are implementing Lean waste reducing techniques, with 10% fully implementing the Lean manufacturing system (EPA, 2003). The flexibility and precision of these systems allows efficient production of small quantities of products at high levels of quality. In a modern world where product personalization is as much a requirement as quality and cost, Lean systems are

essential. Even high volume/low mix companies without the need for enhanced process flexibility, find that Lean systems are justified by the resource efficiency and quality benefits alone.

Traditionally, manufacturers believed there was a trade-off between cost and quality, cost and lot size. Essentially, building a lot of the same product quickly, without regard to quality was the paradigm of traditional “mass production” manufacturing. It was the Japanese, in particular Toyota, who pioneered Lean manufacturing that challenged both of these assumptions. In essence, they saw defects as waste and put in place methods to prevent defects rather than inspection techniques to catch them at the end of the process. Likewise, they viewed over-production as wasteful, and focused on reducing process set-up times, so that they could economically produce smaller quantities of products efficiently that coincided with actual customer demand (Hayes et al, 1984, Skinner, 1974).

The success of Japanese manufacturing led many scholars to research these methods in the 1980's and 1990's, (see for example Monden, 1983, Schonberger, 1982, Ohno, 1988, Ishikawa, 1985, Juran et al, 1988). Early articles and books on Lean manufacturing focused on Lean waste reducing techniques and gave little attention to the management system aspects of this system. For the early observers of Lean companies like Toyota in Japan, it was obvious to see the waste reducing techniques in practice out on the factory floor (i.e. kan ban systems, work cells). It was far less obvious to observe the

management system that led to the creative culture that developed and sustained these techniques.

Part of the problem was that by the time American and European observers came to Japan to observe these Lean plants, the management systems were so much a part of the culture that they did not stand out to the observers or even the host companies as worth mentioning (Womack, 1996). However it became clear after companies tried for decades to implement the waste reducing techniques, that these solutions were not sustainable, and the companies implementing them were not achieving the same Lean results as they saw in Japan. As a result, during the 1980s, interest in Lean waste reducing techniques, often referred to as Just-in-time, began to wane.

During this same period there was considerable research into managerial philosophies (Chase, 1980, 1987, Amoake-Gyaampah, 1989, Neely, 1993, Miller, 1981, Filippini, 1997). The Total Quality Management philosophy suggests that the quality of management was as important, if not more important, than the management of quality. Combining all of these approaches into a single manufacturing strategy led to the startling revelation that there was no longer a trade-off between quality, productivity and flexibility. Lean factories manufacture a wide range of models, while maintaining high levels of quality and productivity. (Panizzolo, 1998) (Krafcik, 1988).

James Womack and Daniel Jones, who coined the term “Lean”, were instrumental in explaining Ohno’s manufacturing system in terms the western

world could understand in their book *Lean Thinking*. Womack describes Lean production as a system that uses less, in terms of all inputs, to create outputs similar to those of traditional mass production systems, while offering increased choices for the final consumer (Womack, 1996). For example, they restated Ohno's forms of waste as follows: mistakes/defects which require rectification, production of items that no one wants so that inventories pile up, processing steps which aren't actually needed, movement of employees and transport of goods from one place to another without any purpose, groups of people in a downstream activity standing around waiting because an upstream activity has not delivered on time, and goods and services which don't meet the needs of the customer. (Womack, 1996).

Womack and Daniels advocated Ohno's view of total waste eliminating by stating "Our earnest advice to lean firms today is simple. To hell with your competitors; compete against *perfection* by identifying all activities that are *muda* (waste) and eliminating them. This is an absolute rather than a relative standard which can provide the essential North Star for any organization." (Womack, 1996)

In the early 1990's with the coining of the term Lean in the release of the in-depth studies of the automotive industry, James Womack promoted a more complete view of Lean manufacturing system, to include the management system that led to a continuous waste reducing culture, which in turn developed and sustained the Lean waste reducing techniques. Interest in Lean manufacturing systems

was reborn, and since that time it is hard to find a book or article that does not talk about the management system and cultural aspects of Lean.

The Womack study found Toyota as the model for Lean manufacturing. As a matter of fact, the title 'Toyota Production System' was commonly used to describe Lean manufacturing systems, before an MIT study coined the term 'Lean Manufacturing', during an in-depth study of the automotive industry in the late 1980's and early 1990's. The MIT study, embodied in the book *'The Machine That Changed The World'*, offered strong evidence that Lean manufacturers had better quality, cost and response time performance than traditional manufacturers. While the study provided examples of Lean manufacturing successes and a philosophical overview of Lean manufacturing, it doesn't clearly spell out the specific best practices of the Lean manufacturing system. Nonetheless, the MIT studies were very popular and led to further research into the constructs of the Lean manufacturing system. In addition to Womack's efforts, several recent scholarly efforts have done a worthy job of defining complete models of the Lean manufacturing system. They are described in detail after an overview of the seven wastes that Lean manufacturing systems strive to eliminate.

Lean Manufacturing Wastes

In the Lean manufacturing vernacular, waste is defined as any human activity which absorbs resources but creates no value: mistakes/defects which require rectification, production of items that no one wants so that inventories pile up,

processing steps which aren't actually needed, movement of employees and transport of goods from one place to another without any purpose, groups of people in a downstream activity standing around waiting because an upstream activity has not delivered on time, and goods and services which don't meet the needs of the customer. (LEI, 2003)

In particular, Lean manufacturing focuses on the reduction of seven wastes. They are: Defects, Over-production, Transport, Waiting, Inventory, Motion, and excess-Processing (D.O.T.W.I.M.P.). The unachievable objective is to eliminate all of these wastes, so that nothing but value added effort exists in the manufacturing process. Reducing these wastes requires considerable changes in the traditional manufacturing operation. Essentially the Lean manufacturing system is a never-ending commitment to reducing the seven wastes mentioned, through the application of best practices. The following is an in-depth definition of the seven Lean wastes. (LEI, 2003)

Defects

A defect occurs when a product or component no longer conforms to the requirement of the customer. This customer can be internal or external to the manufacturing operation. At a minimum, a defect requires rework to resolve the problem. If the defect makes it to the customer, this will strain customer-supplier relations. Defects are wasteful because they are non-value added in nature, and require additional non-value added use of labor and materials to resolve them. In addition, defects create forms of wastes. (LEI, 2003)

For example, defects cause excess processing that would not have been needed if the defect did not occur in the first place. Occurrence of defects often slows or stops the progress of an assembly line causing other processes to *wait* until the defect generating process is resolved. If a product makes it to a customer and must be returned, this leads to unnecessary *transportation*. Transportation leads to emission of *green house gases* and use of *energy*. If a product requires rework or in the worst case needs to be scrapped, then *excess processing* is required. Excess processing requires additional *energy*. If the process uses *hazardous materials and/or water* in processing or cleaning the product, additional amounts of these resources are required. Product that is scrapped becomes *solid waste*, which may also have *hazardous waste* characteristics. (LEI, 2003)

Over-production

Over-production occurs when production output exceeds actual customer orders. Over-production is considered the greatest form of waste in the Lean manufacturing philosophy. The reason for this is because overproduction can lead to the generation of all other forms of Lean wastes (figure 1). If production quantities exceed customer orders, the manufacturer incurs several risks. At a minimum, the manufacturer is exposed to possible customer engineering changes that may require teardown, rework, and even scrapping the product. It is also quite possible, in this era of rapid change, that the product will become obsolete or unwanted while waiting for the next order and need to be severely

discounted and even scrapped completely. As mentioned earlier, scrap generates solid and possibly hazardous waste. (LEI, 2003)

In addition, over-production generates excess *inventory* that must be stored until the customer needs it. This inventory must be *transported* to a safe storage location. Excess inventory in the form of work in process, requires production operators to move this WIP either out of the way or to the next process, leading to excessive *motion*. Transportation and storage require energy usage, and generation of green house gases. Generation of excess inventory consumes capacity, which means other processes and other customer orders must *wait*, until processing is complete. (LEI, 2003)

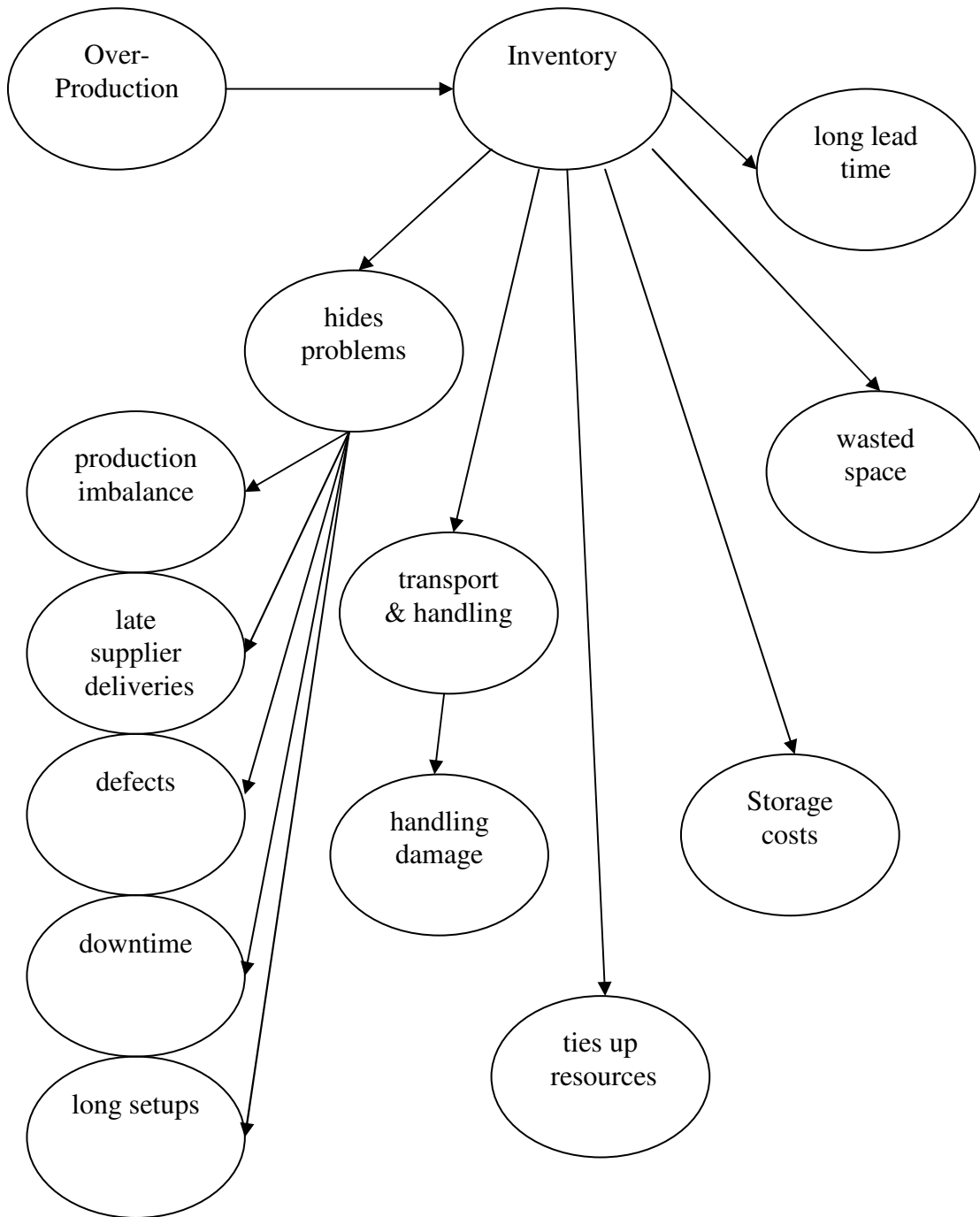


Figure 1. Over-Production Generates All Other Lean Wastes (LEI, 2002)

Transportation

Transportation is wasteful because it is non-value added. In the ideal Lean manufacturing process, all processes are next to each other. And, in the Lean model, manufacturing operations should be close to suppliers and customers. Transportation leads to excess operator motion, which can lead to injury. If transportation requires a vehicle or conveyor, this probably leads to energy use, and green house gas emissions. In addition, excessive transportation implies that processes are far from each other. Distance impedes communication, critical for quality feedback that can prevent or at least minimize defects. Also, distance leads to inventory, due to the impractical nature of moving small amounts of parts or products over great distances. In fact, the greater the distance, the greater the inventory build-up prior to transport. (LEI, 2003)

Waiting

Waiting occurs when processes are not balanced. If machines and operators are waiting either for a preceding process to deliver material (starved) or for a proceeding operation to take material (blocking), then they are not producing value. Machines that are idling, waiting to produce, may still consume energy, consume water and generate hazardous and green house emissions. (LEI, 2003)

Inventory

An analogy is made in the Lean manufacturing philosophy that compares inventory to water. The water/inventory hides, like rocks under the water,

manufacturing problems such as machine breakdowns, absenteeism, imbalance, defects, long set-up times, etc. Of course, hiding the problems does not keep them from causing trouble, it only makes it harder to find the root causes and fix them. Lowering the inventory steadily exposes the problems, and allows the company to deal with them once and for all. (LEI, 2003)

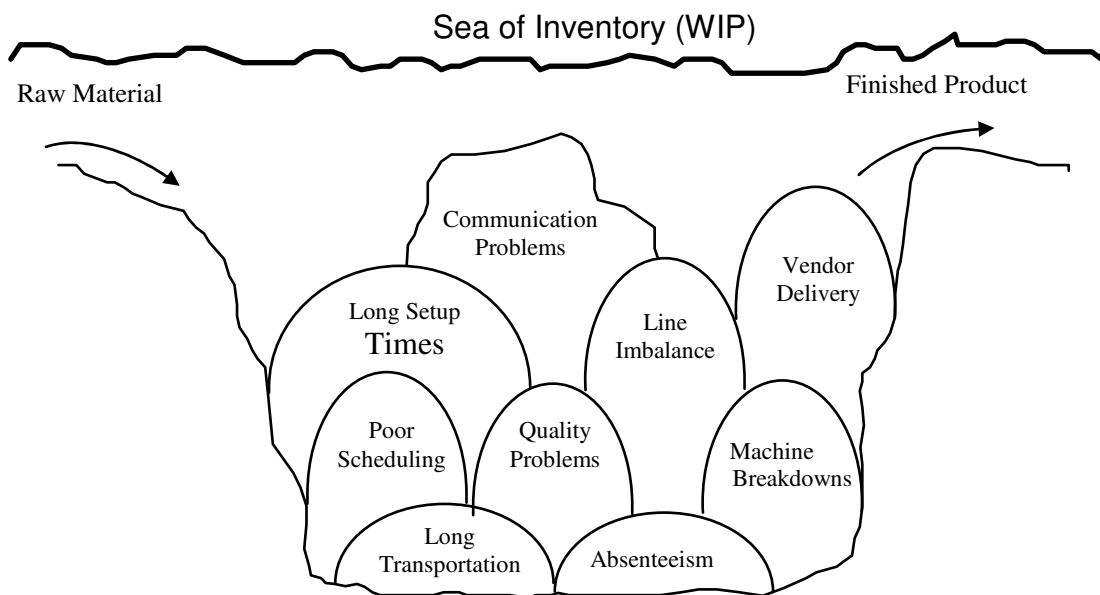


Figure 2. The Analogy of Inventory to Water (LEI, 2003)

Motion

Motion in the Lean philosophy is any unnecessary human movement.

Unnecessary motion is non-value added and consumes human energy that could be used more productively. Unnecessary motion can often lead to injury as well.

At a minimum it leads to fatigue, which causes defects and all of the ills that go

with defects. If excess motion is required to move product from one operation to the next, either inventory will build or the operator will spend a great deal of time moving individual units from one operation to the next. Ideally, Lean manufacturing work design minimizes unnecessary motion so that an operator can build a quality product with the least amount of effort. (LEI, 2003)

Processing (excess)

Too much of a good thing is not always a good thing. Sometimes an operator will strive to make a perfect part, surpassing the customer's requirement. While their intentions are good, over-processing can lead to defects. An example of this is applying too much heat to a solder joint to make it perfect, beyond customer requirements, and burning up the electronic component in the process. In addition, excess processing takes time that could be spent on value added processing. Slowing down a process causes proceeding processes to wait and preceding operations to either wait or build inventory. It requires excess operator motion. If excess processing requires any machinery, it wastes energy and generates emissions. Excess processing also causes consumption of water or hazardous materials as well. (LEI, 2003)

As mentioned previously, the objective of the Lean manufacturing system is to identify and reduce the aforementioned seven wastes. Since the mid-1940's, when Toyota pioneered this new manufacturing system, many innovative practices have been developed to realize this objective. Researchers and practitioners alike have tried to refine these practices into a set of "best" practices

that are together effectively identify and eliminate wastes and are generally applicable to most, if not all, manufacturing operations. The next section attempts to define a working set of best practices for purposes of this doctoral study, based on preceding scholarly research.

Review of Lean Manufacturing System Models

In reviewing past and present Lean research, there appears to be an evolution of research focus. Early studies focused on the characteristics of production processes of Lean companies, such as production planning and process and equipment solutions. Research focus then began to look at the functions that support production operations, such as Human resources and Product design. More recently, research focused on the extended enterprise, including customer relations and supplier relations in the Lean Enterprise. (Sakakibara, Flynn, Schroeder, Morris, 1992, Panizzolo, 1998, Womack, 1996)

The most recent research (SAE, 1999, Liker, 2004, Shingo, 2003, SME, 2006) emphasizes the necessity of management commitment and trust in developing and sustaining a Lean culture. Each research area builds on the next, emphasizing the importance of developing all areas of the business to realize true Lean system potential.

The literature review of Lean manufacturing best practices focuses on several studies that define Lean manufacturing as a system of complementary best practices. Too many people have mistakenly characterized Lean manufacturing

as a short list of best practices implemented on the factory floor. In reality, if all elements of the Lean system are not addressed, the factory floor best practices are at best short lived and the entire system is unsustainable. This part of the literature review begins with the studies that promoted the system nature of Lean manufacturing and are also the studies that coined the term “Lean”. These studies performed by an MIT research team led by James Womack are instrumental in defining the principles of the Lean manufacturing system. The review of the Womack led studies is followed by more recent studies that actually do a far better job of specifying the specific components/best practices of the Lean system.

The Womack Model

As mentioned in the introduction of this section, James P. Womack led an M.I.T. study of the automotive industry that led to the creation of the term “Lean manufacturing”. The study, performed in the late 1980’s and early 1990’s, compared the practices of Japanese automotive manufacturers that pioneered the Lean manufacturing system against the practices of American and European manufacturers (Womack, 1996). This research team then conducted another study in the mid-1990’s that took a more global look at Lean manufacturers and attempted to capture their common best practices (Womack, 1996). The Womack studies identified 5 core principles of Lean manufacturing. They are specifying value, identifying the value stream, flow, pull, and perfection.

Specify Value: Value is defined by the customer and is the goods and/or services that the customer pays for. Anything that does not directly contribute to the creation of value is considered waste in the Lean philosophy. This concept of value to the Lean manufacturing system is akin to quality in the Total Quality Management system whereby quality and value are ultimately defined by the customer.

Identify the Value Stream: The value stream is the set of all the specific actions required to bring products or services to the customer. Mapping the value stream helps companies identify value added steps versus steps that are wasteful. Once wasteful steps are identified, they are targeted for reduction by applying a variety of Lean manufacturing best practices.

Typically, value stream steps are grouped in three categories: Value added (e.g. transformation of raw material into saleable product), non-value added but necessary for the time being (e.g. quality inspection that is catching defects before going to the customer), and non-value added and immediately removable (e.g. excess travel distance between operations that can be eliminated by simple improvements to plant layout).

It should be noted that the Womack studies do not clearly stipulate best practices used to reduce waste. Fortunately, other studies in the literature review do a better job of detailing Lean manufacturing system best practices. (Womack, 1996)

Flow: Once value added steps are identified in the value stream and wasteful steps are targeted for reduction, the next step is to make product and information flow freely from value added step to value added step. The speed of this flow through the value stream, often termed cycle time, defines the responsiveness to customer needs.

The concept of flow challenges the concept of economic order quantity (EOQ). In the flow model, emphasis is placed on only building exactly what the customer needs and moving that quantity of product or information through the value added steps without delay. In the EOQ model, emphasis is placed on building larger batches of products at each stage in the process in order to maximize machine utilization and minimize machine changeover.

Unfortunately, larger batches lead to larger levels of work in process (WIP) inventory that leads to longer cycle times. Shorter cycle time relies on more frequent changeovers, so Lean manufacturing practices were developed to reduce changeover/set-up time. For example the Single Minute Exchange of Die (SMED) approach was developed at Toyota to reduce changeover times of all tooling to less than ten minutes.

Pull: “Push” versus “pull” are simple concepts with profound effects on cycle time. From an enterprise perspective, “pull” means that a product is only built when there is an actual customer order for that product. Push means that products are built in anticipation of product demand. The latter assumes significant delays in the supply chain and therefore is relegated to forecasting and assumptions. The

former assumes short cycle times and quick response to a customer's needs. From an internal factory perspective "push" is a term used to describe traditional batch manufacturing where batches of products are produced at each operation's rate and then staged for the next operation for the next processing step. Pull systems internal to the factory control each stage of production by only allowing preceding operations to produce when the next operation needs parts. This lowers WIP and shortens cycle time.

The Panizzolo Model

The Panizzolo study (1998) interviewed leading European Lean manufacturers to understand the diffusion process of Lean manufacturing best practices. The Panizzolo study (1998) found that Lean manufacturing system deployment began in the core production functions (Production Control and Process and equipment). Then, implementation moves upward into the manufacturing support functions (Product design, Human resources, Management strategy), and then eventually outwards to the extended enterprise (supplier and customer relations).

It should be noted that Panizzolo (1998) found that amongst recognized leaders in Lean manufacturing, most had fully implemented Lean best practices in the core production functions. Diffusion of best practices in the support functions was partial, and most companies had insignificant levels of diffusion of best practices in the extended enterprise. The Lean best practices that Panizzolo studied in particular are organized categorically in the following table.

Table 1. Best Practices at European Lean Manufacturers

Human Resources	HR1	multifunction workers
	HR2	expansion of autonomy and responsibility
	HR3	few levels of management
	HR4	employee involvement in cont. improvement
	HR5	work time flexibility
	HR6	team decision making
	HR7	worker training
	HR8	Pay for performance, innovative appraisal
Process and Equipment	PE1	setup reduction
	PE2	flow lines
	PE3	cellular manufacturing
	PE4	rigorous preventative maintenance (TPM)
	PE5	“error proof” equipment (poka-yoke)
	PE6	progressive use of new process technologies
	PE7	process capability (6 sigma)
	PE8	order and cleanliness (5S)
	PE9	continuous reduction of cycle time (JIT)
Production Planning and Control	PPC1	leveled production (JIT)
	PPC2	synchronized scheduling (mix model)
	PPC3	mixed model scheduling
	PPC4	under-capacity scheduling
	PPC5	small lot sizing
	PPC6	visual control of shop floor (visual factory)
	PPC7	overlapped production
	PPC8	pull flow control
Product Design	PD1	parts standardization
	PD2	product modularization
	PD3	mushroom concept (?)
	PD4	design for manufacturing
	PD5	phase overlapping
	PD6	multifunctional design teams
Supplier Relationships	SR1	JIT deliveries
	SR2	open orders (blanket orders)
	SR3	quality at the source
	SR4	schedule/MRP sharing
	SR5	supplier involvement in quality improvement
	SR6	reduction in vendor base
	SR7	long-term contracts
	SR8	total cost supplier evaluation
	SR9	supplier involvement in product design
Customer Relations	CR1	reliable and prompt deliveries
	CR2	commercial actions to stabilize demand
	CR3	capability and competence of sales network
	CR4	early information on customer needs
	CR5	flexibility in meeting customer requirements
	CR6	serviced enhanced product
	CR7	customer involvement in product design
	CR8	customer involvement in quality programs

SAE J4000 Model

In 1999 the Society of Automotive Engineers (SAE) released a Lean Operations Best Practices Specification titled the J4000. The J4000 specification includes the Lean best practice categories identified in the Panizzolo study (i.e. production processes, support functions, extended enterprise). In addition, the J4000 has a complete section devoted to Management Commitment. In particular the J4000 indicates that leading Lean manufacturers exhibit the following management commitment best practices:

- Lean is considered a strategic tool essential to the company's competitiveness.
- Structured Lean policy statements are in place.
- Lean goals and objectives are defined.
- Lean philosophy is communicated to all, and employees are vigorously trained on lean practices.
- Senior officials exhibit strong leadership of Lean deployment.
- There are regular Lean progress reviews and managers are accountable for lean progress.
- Meaningful incentives are in place to reward Lean progress.
- A non-blaming, performance oriented, process-driven organizational atmosphere exists.
- No employee has reason to perceive his livelihood is in jeopardy by contributing to organizational Lean progress.
- Management has chosen to adhere to Lean principles in the face of short term operating objectives inconsistent with Lean progress.

SAE developed the J4000 based on several years of research assessing the best practices of recognized Lean manufacturers from a variety of industry sectors. Each best practice was validated by identifying its existence in at least three of the leading Lean companies. The validation efforts were documented in

SAE document RR3003, which I have reviewed for completeness. The end result is a generalized set of best practices that all manufacturers aspiring to become Lean should implement.

The J4000 specification is structured as a survey companies can use to benchmark their performance against the best practices of industry's Lean manufacturing leaders. SAE began the best-practices survey in 1998 and developed a comprehensive measurement template and methodology to evaluate companies that had been identified as model Lean companies. The companies were selected based on input from automaker executives, industry analysts, and academics, as well as independent research. (SAE, 1999)

It stands to reason that SAE would develop a Lean specification since the automotive industry has been under the greatest competitive pressure to adopt Lean systems. The MIT study on the automotive industry in the early 1990s, which coined the term 'Lean', found that Lean manufacturing principles were the leading reason for Japanese dominance of the automotive industry during the 1980s. (Womack, 1996) Now most automotive manufacturers in the U.S. are transforming their traditional manufacturing systems to Lean systems. (Rothenberg, 2001) Popularity of these studies and successful cases of Lean manufacturing systems has led to broad based acceptance of the Lean manufacturing system throughout all manufacturing sectors. Both the research and application of best practices concisely culminate in the J4000 Lean manufacturing system best practices specification, making it an ideal tool

assessing a company's "Leanness". The sections of the J400 specification dealing with Lean best practices are listed below for completeness. In parentheses are the weighting factors assigned by SAE to the respective sections, indicating the relative importance of that section to the overall effectiveness of the Lean system. (SAE,1999)

Table 2. SAE J4000 Criteria

4) Management/Trust (25%)

- 4.1) Continuous Progress in Implementing Lean Operating Methods is the organization's primary tool pursuing its strategic objectives.
- 4.2) Structured policy deployment techniques are used to plan the organization's Lean deployment.
- 4.3) Lean progress targets are defined and have been effectively communicated
- 4.4) Knowledge of the philosophy and mechanics of Lean operation has been obtained and effectively communicated.
- 4.5) The organization's senior managers are actively leading the deployment of Lean practices (senior managers of the site)
- 4.6) Lean progress is reviewed by senior management against planned targets on a regular basis.
- 4.7) Meaningful incentives that reward organizational Lean progress are in place
- 4.8) Individual managers' performance is evaluated and rewarded relative to Lean progress
- 4.9) A non-blaming, performance oriented, process-driven organizational atmosphere exists
- 4.10) There is regular, direct personal involvement by senior management with operating workforce concerning Lean practices
- 4.11) Consistent policy for disposition of individuals made surplus by lean progress in place and followed
- 4.12) No employee has reason to perceive their livelihood to be jeopardized by contributing to organizational lean progress
- 4.13) Management has chosen to adhere to Lean principles in the face of short term operating objectives inconsistent with Lean progress

Table 2. (Continued)

5. People (25%)

- 5.1) Adequate training resources are provided and paid employees training time is made available.
- 5.2) The training syllabus includes training in the Lean-specific tools and measurable suitable to the organization's needs, at all level within the organization.
- 5.3) Training is conducted as scheduled, records are not kept or are inadequate or no measure of training effectiveness exists.
- 5.4) Organization is structured to correspond to the structure and sequence of the value chain through the enterprise.
- 5.5) Each employee participates in the structure as corresponds to his work role
- 5.6) Labor and employment policies and agreements are in place which allow Lean progress within the organization
- 5.7) Team authority level and accountability level is clearly defined.
- 5.8) Employee development through quality circles/Continuous Improvement (CI) teams is encouraged and supported at all levels.
- 5.9) Team is accountable for CI in its segment of the value chain
- 5.10) Team decision-making authority and authority to act corresponds to the level of team accountability
- 5.11) Management does not supersede team decisions and actions when within the teams authority
- 5.12) Management supports team decisions and actions with required resources, consistent with good business practices.

6. Information (Sections 6,7 & 8 together equal 25%)

- 6.1) Adequate and accurate operating information is available to members of the organization as needed.
- 6.2) Knowledge is shared across the organization
- 6.3) Data collection and its use are the responsibility of the individuals most closely associated with that part of the process
- 6.4) The operating financial system is structured to present correctly the results of lean progress

7. Supplier/Organization/Customer Chain

- 7.1) Both suppliers and customers participate at the earliest possible stage in the organization's undertaking of a product/process project
- 7.2) Both suppliers and customers are appropriately represented on the organization's product/process/project teams.
- 7.3) Both suppliers and customers participate in regular reviews of product/process/project progress.

Table 2. (Continued)

7.4) Effective incentives for supplier, organization and customer are in place that reward shared performance improvements or cost reduction

8. Product

8.1) Product and process design is conducted by fully integrated teams with team representation by all stakeholders.

8.2) Cost, performance and attribute specifications for product and process are unambiguous, measurable and agreed to by all stakeholders

8.3) Product and process design is conducted from a life-cycle systems approach

8.4) Product design and process capability parameters are set to be as robust as possible, consistent with good business practice.

8.5) Provision is made for continuity of team knowledge for duration of product/process launch.

8.6) Lead times for product and process design are measured and being continually

9. Process/Flow (25%)

9.1) The work environment is clean, well organized and audited regularly against standardized 5S practices.

9.2) An effective planned preventative maintenance system is in place with the appropriate maintenance conducted at the prescribed frequencies for all equipment

9.3) Bills of material are accurately catalogued and standard operations are accurately routed, timed and have been value engineered.

9.4) Value stream is fully mapped and products are physically segregated into like-process streams.

9.5) Production sequence is Load-smoothed to customer Pull, and Demand is leveled over the manufactured planning period.

9.6) Process flow is controlled by visual means, internal to the process.

9.7) Process is in statistical control with capability requirements being met and process variability continually reduced.

9.8) Preventative action, using disciplined problem-solving method, is taken and documented in each instance of product or process nonconformance.

9.9) Production flow commences only upon receipt of shipment order. Process flows at takt time rate, in single unit quantities, to point of customer receipt.

9.10) Procedures are in place and being followed that result in continually shorter changeover times and smaller lot sizes.

9.11) Factory layout requires continuously synchronous flow of material and in-factory product travel distance is continually reduced as flow path is improved. (SAE,1999)

The Liker Model

Dr. Jeffery Liker has been studying the Toyota production system for twenty years and was granted full access to Toyota executives, employees, and factories, both in Japan and the United States to develop a book explicitly detailing the Toyota Production System which is synonymous with Lean manufacturing. In his recent book (*The Toyota Way, 2004*) Dr. Liker reveals the fourteen principles that comprise the Lean manufacturing system.

Dr. Liker's description of the Lean system is similar to James Womack's, but provides considerably more detail in all aspects of the manufacturing system. Dr. Liker's books on the Toyota way are among the top selling books on the subject of Lean. This is a strong indication that practitioners and industry leaders are yearning for more systems based understanding of Lean manufacturing. For completeness, the following table summarizes Dr. Liker's fourteen principles that depict the Lean manufacturing system.

Table 3. The Fourteen Toyota Way Principles

The Fourteen Toyota Way Principles
<i>1) Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals</i>
Have philosophical sense of the purpose that supersedes any short-term decision making.
Generate value for the customer, society, and the economy - it is your starting point. Evaluate every function in the company in terms of its ability to achieve this.
Be responsible. Strive to decide your own fate. Act with self reliance and trust in your own abilities.

Table 3. (Continued)

<i>2) Create continuous process flow to bring problems to the surface</i>
Redesign work processes to achieve high value-added, continuous flow. Strive to cut back the to zero the time that any work project is sitting idle or waiting for someone to work on it.
Create flow to move material and information fast as well as to link processes and people together so that problems surface right away.
Make flow evident throughout your organizational culture.
<i>3) Use "pull" systems to avoid overproduction</i>
Provide your downstream customers in the production process with what they want, when they want it and in the amount that they want.
Minimize your work in process and warehousing of inventory by stocking small amounts of each product and frequently restocking based on what the customer actually takes away.
Be responsive to the day-by-day shifts in customer demand rather than relying on computer schedules and systems to track wasteful inventory.
<i>4) Level out the workload</i>
Eliminating overburdened people and equipment and eliminating unevenness in the production schedule.
Work to level out the workload of all manufacturing and service processes as an alternative to the stop/start approach of working on projects in batches that is typical.
<i>5) Build a culture of stopping to fix problems, to get quality right the first time</i>
Quality for the customer drives your value proposition.
Use all the modern quality assurance methods available.
Build into your equipment the capability of detecting problems and stopping itself. Develop a visual system to alert team and team leads that a machine or process needs assistance.
Build into your organization support systems to quickly solve problems and put in place countermeasures.
Build into your culture the philosophy of stopping or slowing down to get quality right the first time.
<i>6) Standardize tasks are the foundation for continuous improvement and employee empowerment</i>
Use stable repeatable methods everywhere to maintain the predictability, regular timing, and regular output of your process.
Capture the accumulated learning about a process up to a point in time by standardizing today's best practices. Allow creative and individual expression to improve upon the standard; then incorporate it into the new standard so that when a person moves on you can hand off the learning to the next person.

Table 3. (Continued)

<i>7) Use visual control so no problems are hidden</i>
Use simple visual indicators to help people determine immediately whether they are in a standard condition or deviating from it.
Avoid using a computer screen when it moves the worker's focus away from the workplace.
Design simple visual systems at the place where the work is done, to support flow and pull.
Reduce your reports to one piece of paper whenever possible, even for your most important financial decisions.
<i>8) Use only reliable, thoroughly tested technology that serves your people and process</i>
Use technology to support people, not to replace people. Often it is best to work out a process manually before adding technology to support the process.
New technology is often unreliable and difficult to standardize and therefore endangers "flow". A proven process that works generally takes precedence over new and untested technology.
Conduct actual tests before adopting new technology in business processes, manufacturing systems, or products.
Reject or modify technologies that conflict with your culture or that might disrupt stability, reliability and predictability.
Nevertheless, encourage your people to consider new technologies when looking into new approaches to work. Quickly implement a thoroughly considered technology if it has been proven in trials and it can improve flow in your process.
<i>9) Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others</i>
Grow leaders from within, rather than buying them from outside the organization.
Do not view the leader's job as simply accomplishing tasks and having good people skills. Leaders must be role models of the company's philosophy and way of doing business.
A good leader must understand the daily work in great detail so he or she can be the best teacher of your company's philosophy.
<i>10) Develop exceptional people who follow your company's philosophy</i>
Create a strong, stable culture in which company values and beliefs are widely shared and lived out over a period of many years.
Train exceptional individuals and teams to work within the corporate philosophy to achieve exceptional results.
Use cross-functional teams to improve quality and productivity and enhance flow by solving difficult technical problems. Empowerment occurs when people use the company's tools to improve the company.

Table 3. (Continued)

<p>Make an ongoing effort to teach individuals how to work together as teams toward common goals. Teamwork is something that has to be learned.</p>
<p><i>11) Respect your extended network of partners and suppliers by challenging them and helping them improve</i></p>
<p>Have respect for your partners and suppliers and treat them as an extension of your business.</p>
<p>Challenge your outside business partners to grow and develop. Set challenging targets and assist your partners in achieving them.</p>
<p><i>12) Go and see for yourself to thoroughly understand the situation</i></p>
<p>Solve problems and improve processes by going to the source and personally observing and verifying data rather than theorizing on the basis of what other people or the computer screen tell you.</p>
<p>Think and speak based on personally verified data</p>
<p>Even high-level managers and executives should go and see things for themselves, so they will have more than a superficial understanding of the situation.</p>
<p><i>13) Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly</i></p>
<p>Do not pick a single direction and go down that one path until you have thoroughly considered alternatives.</p>
<p>Discuss problems and potential solutions with all of those affected, to collect their ideas and get agreement on a path forward.</p>
<p><i>14) Become a learning organization through relentless reflection and continuous improvement</i></p>
<p>Once you have established a stable process, use continuous improvement tools to determine the root cause of inefficiencies and apply effective countermeasures.</p>
<p>Design processes that require almost no inventory. Expose waste and have employees use a continuous improvement process to eliminate it.</p>
<p>Protect the organization knowledge base by developing stable personnel, slow promotion, and very careful succession systems.</p>
<p>Use reflection at key milestones and after you finish a project to openly identify all the shortcomings of the project. Develop countermeasures to avoid the same mistakes again.</p>
<p>Learn by standardizing the best practices, rather than reinventing the wheel with each new project and each new manager.</p>

The Shingo Prize Model

The Shingo Prize for Excellence in Manufacturing is named for Japanese industrial engineer Shigeo Shingo, who distinguished himself as one of the world's leading experts in improving manufacturing processes. Dr. Shingo has been described as an "engineering genius" who helped create and write about many aspects of the revolutionary manufacturing practices which comprise the renowned Toyota Production System.

The Prize was established in 1988 to promote awareness of Lean manufacturing concepts and recognize companies in the United States, Canada, and Mexico that achieve world-class manufacturing status. The Shingo Prize philosophy is that world-class business performance may be achieved through focused improvements in core manufacturing and business processes.

The Shingo Prize recognizes organizations that use world-class manufacturing strategies and practices to achieve world-class results. Applicants are scored based on the point systems shown in figure 3, and applicants with high scores receive a site visit from a team of five or more expert examiners. All applicants who receive a site visit will be publicly recognized as Finalists. Recipients of the annual Shingo prize itself are selected from this prestigious group.

The figure below depicts the Shingo Prize criteria in model form. The complete Shingo prize criteria is in appendix A. (Shingo, 2003)

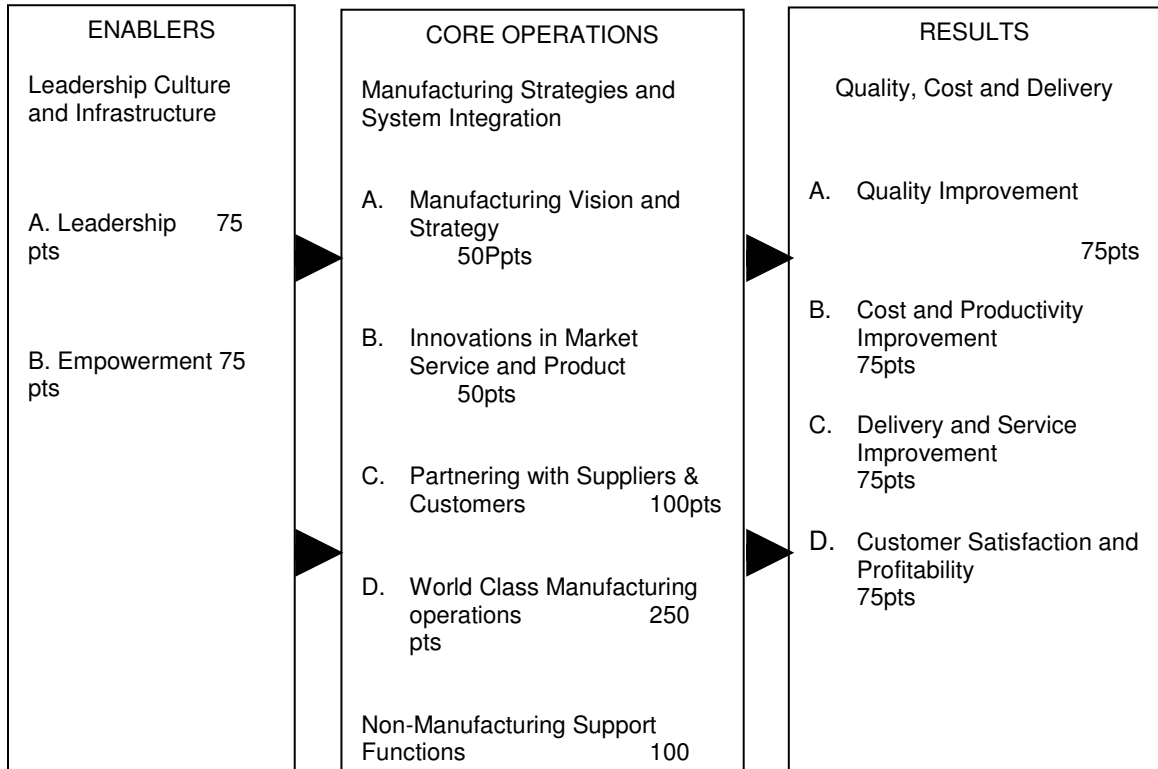


Figure 3. The Shingo Prize Model

The Shingo Prize achievement criteria provide a framework for identifying and evaluating world-class manufacturing competence and performance. The criteria comprise a business systems model for manufacturing excellence, organized into principle sections as pictured in figure 3.

The world-class strategies and practices that are referred to in the criteria are presented in sections I through III of the guidelines. World-class results are discussed in sections IV and V. There are expected measurements for quality, cost, delivery and business results (See appendix A). (Shingo, 2003)

The Shingo criteria are an excellent example of how the understanding of the Lean manufacturing system has evolved from a collection of shop floor best practices to a robust Manufacturing system. However, what has not evolved during this same period is the definition of waste from a Lean perspective. Except for the studies mentioned in the beginning of the literature review, little attention has been given to the relationship of Lean system wastes and environmental waste. The next section of the literature review will attempt to define environmental wastes and the Green manufacturing system best practices used to reduce them.

Green Manufacturing Literature Review

Background

Manufacturers are fortunate to live in a time when they can be part of the environmental solution rather than the environmental problem. Market conditions and regulatory pressure offer great incentives for Green manufacturing and great risks for those that continue polluting the environment. Cleaner processes, conservation of material and energy, and the elimination of waste in general make good business sense. In other words, reducing environmental wastes reduces costs and risks of doing business.(Montabon, 2001)

The costs and liabilities associated with environmental waste are not restricted to legal issues, although these can be substantial. Several other reasons exist for companies to consider going green. The cost to purchase and dispose of

hazardous materials continues to rise. Market resistance to environmentally harmful products continues to increase. Environmental consciousness of consumers continues to rise. Regulatory hostility increases for known polluters.

The primary wastes targeted by a typical Green manufacturing system include hazardous materials, green house gases, solid wastes, water usage, and energy. Like Lean manufacturing there are a series of best practices used to reduce these wastes. Commitment to reducing environmental waste through the implementation of best practices is the essential core of a Green manufacturing strategy.

A fully implemented Green manufacturing system affects every function of the manufacturing business. Marketing, accounting, human resources, supplier and customer relations, design and production are all involved in a fully integrated Green manufacturing system. However, it is the rare company that has taken its Green system to these limits. Most manufacturers begin in the manufacturing process and work their way upward and outward over time. (Scallon, Sten, 1997) In order to assure general applicability of this study, emphasis will be placed on the core production operations and those that directly affect them. This will help to keep the study to a manageable scope.

Unlike the Lean manufacturing system, which is based on the Toyota Production System established in the 1950's, the Green manufacturing system is in its infancy of development and standardization. Arguably, it is not mature enough to be called a system at all. Thus, it is difficult to develop a comprehensive yet

generally applicable model for Green manufacturing. However, several common themes and best practices do emerge in looking at leading studies on the subject and these will be explored shortly.

To help define a Green manufacturing System, it is helpful to understand its objective, which is to reduce environmental waste. In order to be more specific, several literature sources were tapped on environmental waste and waste metrics. A working definition of hazardous waste was developed in 1985 under the United Nations Environment Program auspices. "... Solids, sludges, liquids and containerized gases, other than radioactive and infectious wastes which, by reason of their chemical activity or toxic, explosive, corrosive, or other characteristics, cause danger or likely will cause danger to health or the environment, whether alone or when coming into contact with other waste ... "Solid wastes comprise all the wastes arising from human and animal activities that are normally solid and are discarded as useless or unwanted." (Tchobanoglous, 1993). Additionally, green house gases are also important environmental wastes to consider in this day and age.

Green Manufacturing Wastes

There are many measures of environmental waste used by manufacturers today. EPA environmental regulations alone have created a need to assess companies' environmental wastes objectively. The following table provides a rather complete set of environmental wastes metrics used by manufacturing and

regulatory agencies to objectively assess and ultimately reduce the environmental impact of manufacturing on the environment (NAE, 1997).

Table 4. Green Manufacturing Wastes

Metric	What is measured	Advantages	Disadvantages
Permit Compliance	Compliance with applicable permits expressed as exceeding permit limits	An essential measure—customers will look first to your compliance with permits	Taken alone, a narrow measure indicating that you are doing only what is required.
Toxic Release Inventory (TRI) Chemical Releases	Over 300 chemicals subject to release annual reporting requirements under SARA Section 313.	Information on release is widely available to the public; an effective way to communicate performance.	Does not cover all important chemicals or industries; focuses on release volume without accounting for differences in toxicity.
33/50 Chemicals	A subset of the TRI chemicals identified by the EPA as priority candidates for voluntary reductions in releases by industry.	A more refined list of chemicals than TRI; companies participating in the 33/50 program and meeting goals will receive public credit.	Leaves out many important chemicals; not clear that a company not participating
Clean Air Act Toxics	189 chemicals listed in the Clean Air Act as air toxics subject to maximum achievable control technology (MACT) standards.	MACT standards will be extremely costly to meet. By reducing or eliminating releases, you avoid very high future costs	Taken alone, like TRI, not a full measure of environmental performance; focuses only on air, creates risk of shifting problem from air to other media
Risk-Weighted Releases	Toxic chemicals weighted by their relative toxicity.	A more realistic depiction of health and environmental effects than unweighted releases.	Toxicity data are frequently highly uncertain; risk-weighted approach has not been generally accepted by key customers-EPA, environmental groups.
Waste per Unit of Production	Percentage of production lost as waste; generally measured by weight.	A very broadly applicable measure that incorporates efficiency in use of resources as well as containment releases to the environment.	No priority established in terms of type of wastes; absent other measures, creates an incentive to focus on high-volume, low-toxicity wastes.

Table 4. (Continued)

Energy Use	Total energy use by all aspects of corporate operations; can be expressed also as carbon dioxide.	A comprehensive measure that focuses attention on efficiency in use of key resources; anticipates possible global warming concerns; readily communicated to customer.	Energy efficiency is important, but not the only basis on which to evaluate environmental performance; other measures also needed.
Solid Waste Generation	Total solid waste going to landfills or other disposal facilities	An important measure in the public mind because of publicity surrounding landfill capacity shortage; often reflects efficiency in resource use.	A very narrow measure of environmental performance; often misinterpreted as the most important criterion to judge performance.
Product Life Cycle	The total impact of a product on the environment from raw materials sourcing through production use and ultimate disposal	The most comprehensive measure of product level impact; a meaningful goal to strive for in resource use efficiency and pollution prevention.	Extremely complex to implement; methodologies are not commonly accepted; claims based on product life cycle analysis are frequently treated with skepticism; difficult to apply at a corporate or unit level.

Green Manufacturing Models

So what does it mean to be a Green manufacturer anyway? Essentially it means that reducing environmental waste is as important as other traditional operational measures such as cost, quality and responsiveness. It implies that the organization embraces continuous environmental improvement in all business functions. It also implies that pollution prevention is regarded as the only reasonable approach to reducing environmental impact, as opposed to 'end-of-pipe' waste containment or transformation.

End-of-pipe strategies may let companies get past regulatory emission hurdles, but this approach is a costly alternative to waste minimization, and does nothing

to reduce the waste of the product after it leaves the factory. Remediation and compliance approaches only apply if a waste can be contained once emitted. Major environmental problems such as ozone depletion, green house gases and loss of arable soil cannot be remediated and must be prevented. The only logical approach to reduce environmental impact is to adopt a continuous process of waste minimization. Companies ignoring environmental issues are in danger of losing market penetration and being viewed as part of the problem and not part of the solution.

There are several additional incentives for management to commit to a Green manufacturing strategy:

- A company can reduce exposure to regulatory pressure and the related fines and criminal charges.
- Green manufacturing solutions improve resource efficiency, lowering the costs of material, energy, water, waste management and disposal.
- Companies that operate in the global economy will benefit from global acceptance of environmentally conscious behavior, thereby reducing trade barriers.
- Consumer pressure for environmentally conscious products is ever increasing. And of course, common sense - an ounce of prevention is worth a pound of cure. (EPA, 2001)

How does a Manufacturer become Green? This is a question of considerable debate. Topics in this area of research are still being defined and new topics are arriving on the scene. In an attempt to define what Green manufacturing actually is, several subjects have been identified that together make up a holistic approach to reducing environmental waste of manufacturing operations: Green manufacturing. These subjects are summarized below in the following Green manufacturing literature review.

Starting at the top of the organization, a Green manufacturing system should include an Environmental Management System (EMS). The EMS defines the corporate environmental policies and procedures that assure good environmental performance. In particular, ISO14001 is the internationally supported model for an EMS. An EMS is very high-level strategic model and does not necessarily directly reduce waste, rather it creates the environment or culture that leads to waste reducing techniques.

When it comes to specific techniques for reducing environmental waste, this is where pollution prevention and waste minimization programs are effective. These tactical programs focused mainly on the operational aspects of the manufacturing firm, help companies create continuous environmental improvement programs with elements such as improvement team structures, tools for identifying and reducing wastes, etc.

In addition there is a specific body of literature on environmentally conscious product and process design, known as Design for the Environment (DfE). This discipline focuses on the engineering side of Green manufacturing. Also, there is a Green accounting discipline, for which one name is Total Cost Accounting. Finally, the newest subject relating to Green manufacturing and without question the most broad based, is Industrial Ecology. So broad is this subject, that by all rights, Green manufacturing is simply a part of it. It also makes for a good topic to discuss first to frame the rest of the Green manufacturing discussion.

Industrial Ecology

The philosophy of Industrial Ecology is so profound that it warrants mention in this literature review in order to provide a broad philosophical framework for the ultimate Green manufacturing system. Industrial ecology attempts to look at industrial systems as ecosystems, whereby the waste of one process becomes the raw material of another: closing the loop of a normally open ended industrial system. As if that was not enough of a challenge, industrial ecology also seeks to find harmony between natural ecosystems and these new industrial ecosystems, creating a sustainable future for mankind. Reid Liefset, of Yale University and editor and chief of the *Journal of Industrial Ecology* firmly states that Industrial Ecology is still very much in the conceptual stages, and thus has limited application in this doctoral study. (Liefset, 2000) But, philosophically it offers some of the most powerful rationale for accelerating the deployment of Green manufacturing systems.

Industrial ecology is the means by which humanity can deliberately and rationally approach, and maintain a desirable carrying capacity, given continued economic, cultural, and technology evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle from virgin material to finished material, component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital. (Liefset, 2000)

Industrial ecology differs from traditional waste minimization and pollution prevention strategies. A single company can make great strides in waste minimization all by itself and perhaps its suppliers, like 3M's pollution prevention pays (3P) program that reduced air pollution by 120,000 tons. Industrial ecology builds on this concept to an industrial ecosystem where the waste byproducts of one manufacture become the inputs to other manufacture, and products and packaging are returned back into the industrial ecosystem when their useful life is over, rather than in a landfill.

The concept of managing materials from raw materials to finished products is common among Lean manufacturers and often referred to as supply chain management. But, supply chain management ends when the product reaches the consumer. Industrial ecology closed the industrial loop and considers additionally how the product makes its way back from the consumer to various stages of the industrial ecosystem. The following figure shows the five life-cycle stages in a typical manufactured product.

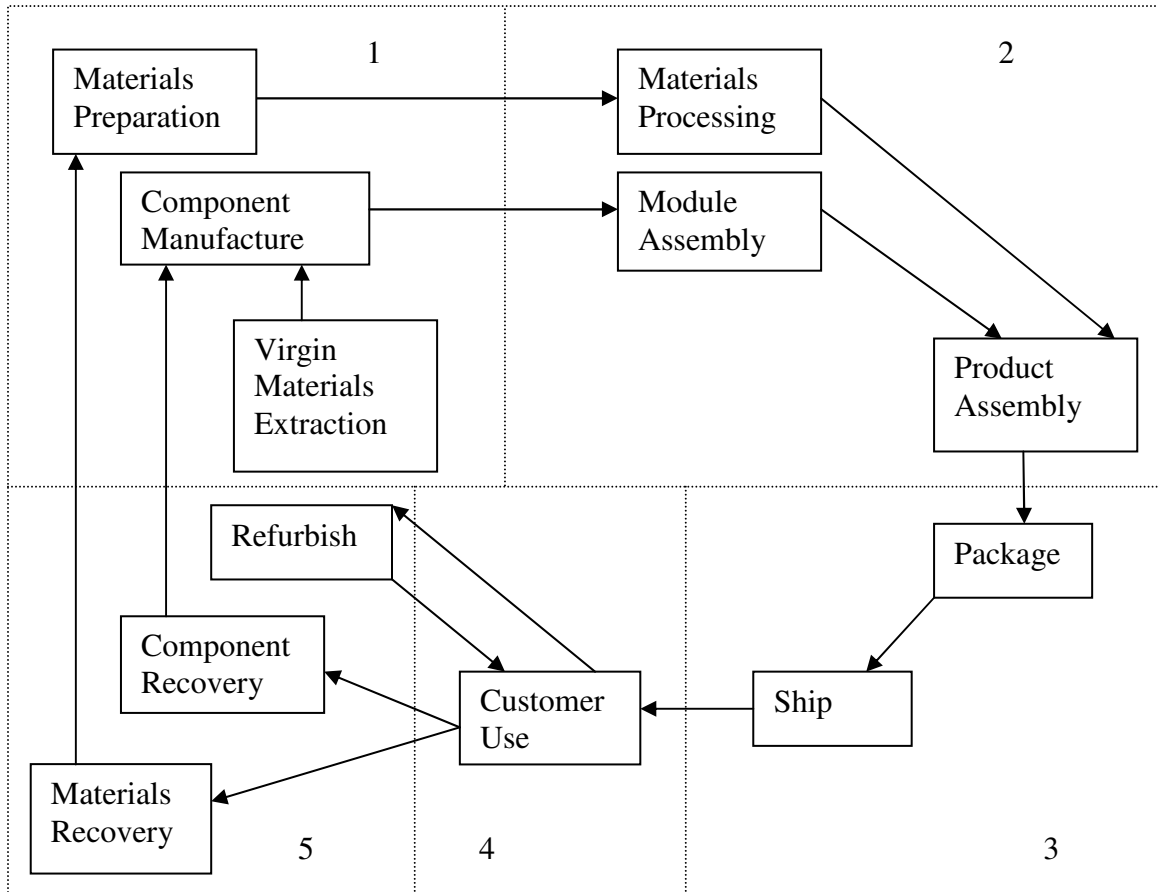


Figure 4. Industrial Ecology Model

Activities in the five life-cycle stages of a product manufactured for customer use. In an environmentally responsible product, the environmental impacts are minimized in each stage, not only stage 2. The long-term goal is to reintroduce all material in discarded products into the resource streams that flow into new products. (Liefset, 2000)

- Stage 1:Pre-manufacture, is performed by suppliers. Generally drawing virgin resources and producing materials and components
- Stage 2:Manufacturing
- Stage 3:Packaging and Transport

- Stage 4: Customer use stage, is influenced by both the user and the degree of continuing manufacturing interaction.
- Stage 5: End of useful life, a product is no longer satisfactory because of obsolescence, component degradation, or changed business or personal decisions. At this point, it is either refurbished or discarded.

Eventually, all five phases will become, in some part, the responsibility of the manufacturer. The emerging vision is that the products minimize their environmental impact throughout all five life cycle stages, from cradle to reincarnation. Ideally, there is no longer a grave commonly known as a landfill. To fulfill the objectives of industrial ecology, manufacturers have to change their thinking from providing a product to providing a product of service. That is to say providing the service a product provides rather than the product itself. In this model manufacturers are responsible for the entire life cycle of the product and thus more encouraged to make products that last longer and are easily remanufactured. (Liefset, 2000)

Consumers are becoming more receptive to the concept of “borrowing” or leasing a product rather than owning it. Automobile leasing is popular and more recently computer leasing is growing. Designers have traditionally considered only the cost to manufacture and the final performance of their designs. The new concern with the environmental approach to the entire product life cycle requires that all life stages be addressed in a structured way.

Green Management System Models

Management Systems became popular in recent decades with the development of international standards for both Quality Management Systems (ISO9000) and

more recently Environmental Management Systems (ISO14001). ISO refers to the International Standards Organization in Geneva, Switzerland. Manufacturing plants are certified to one of these International standards by independent registrars, upon meeting the requirements stated in the ISO Management system standard. (Russo, 2001)

Implementing an environmental management system (EMS) is a process by which an organization's management identifies regulated and unregulated environmental aspects and impacts of its operations, assesses current performance, and develops targets and plans to achieve both significant and incremental environmental improvements. Environmental aspects are human or industrial activities, products, or services that can interact with the environment. Environmental aspects are evaluated as to whether they can cause significant environmental impacts or changes.

An EMS integrates environmental management into the organization's overall management system by identifying the policies, environmental targets, measurements, authority structures and resources necessary to produce both regulatory compliance as well as environmental performance "beyond compliance." A continual improvement cycle is established through this process. (ISO, 2002)

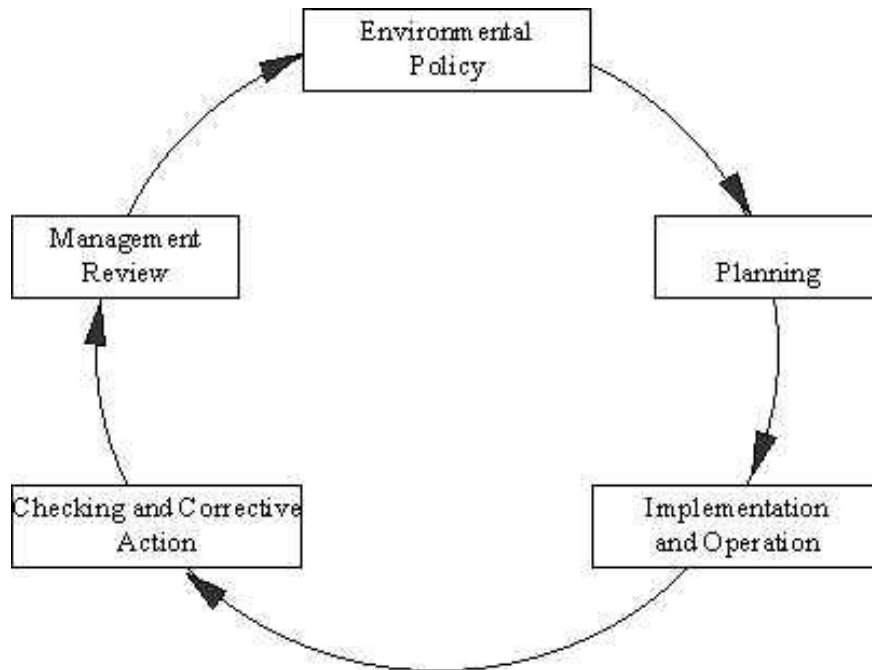


Figure 5. EMS Continual Improvement Cycle

ISO 14001 has been gaining in popularity as the model for Environmental Management System since it was finalized in 1996. It is an ideal measure of an environmental management system in that it is general enough to apply to any business environment, yet specific enough to assure that the right set of policies and procedures are in place to drive Green waste reducing activity.

As with any company wide improvement program, environmental management must begin at the top. Management commitment and a comprehensive management system that establishes the proper structure for Green manufacturing are the essential first steps to becoming a Green manufacturer. This is similar to establishing a Total Quality Management program (TQM). The ISO9000 series Quality Management System (QMS) specification, offers

companies a model for establishing a company wide TQM program. ISO14000 provides a similar blue print for companies attempting to become Green. (ISO, 2002)

The ISO 14001 sanctioned EMS provides the necessary structure for sustainable environmental improvement. The ISO 14001 standard focuses on process not performance standards. The EMS defines the corporate environmental policies and procedures that assure good environmental performance. Documenting the environmental policies and procedures, and identifying those responsible for enacting them, clearly defines everyone's role in the organizations toward improving environmental performance. (ISO, 2002)

It is difficult, given the broad scope of industry, to set international standards for environmental performance. This is the job of regulatory agencies. The role of ISO 14000 is to standardize the system a company has in place for environmental management. It can be considered a proactive approach if it can be inferred that a well developed and managed environmental management system leads to good environmental performance. ISO 14000 attempts to lay a foundation for good environmental performance, and also attempts to help level the playing field for environmental performance globally. (ISO, 2002). A specific example of how ISO 14000 drives management commitment to Green manufacturing is illustrated in the following environmental policy requirement.

Top management shall define the organization's environmental policy and ensure that it is appropriate to the nature, scale and environmental impacts of its activities, products or services. It includes a commitment to continual improvement and prevention of pollution. It includes a commitment to comply with relevant

environmental legislation and regulations, and with other requirements to which the organization subscribes. It provides the framework for setting and reviewing environmental objectives and targets. The policy is documented, implemented, maintained and communicated to all employees, and is available to the public (ISO, 2002)

The reason for an international standard is because there has been growing interest in comprehensive environmental programs and a proliferation of national EMS standards in recent years. Most notably are the EMAS and BS7750 standards that ISO 14000 is based upon. A single international standard will simplify international trade issues. Eventually, having a certified EMS will be the requirement for doing business, as in the case of ISO 9000 – Quality Management System standard. Standardizing this process will eliminate the need for a company to have its EMS registered in every country where it does business.

The European Union (EU) is imposing stronger environmental requirements on companies that conduct trade with EU nations and require certain environmental conditions are met before products can be shipped into the EU, such as lead free solder in electronics and provisions for recycling of products shipped into the EU. (ROHS, 2006). Perhaps one day in the very near future companies conducting business with the EU will also need to be ISO14001 certified. The following diagram shows the interrelationship between ISO 14000 documents (Goetsch, 2001):

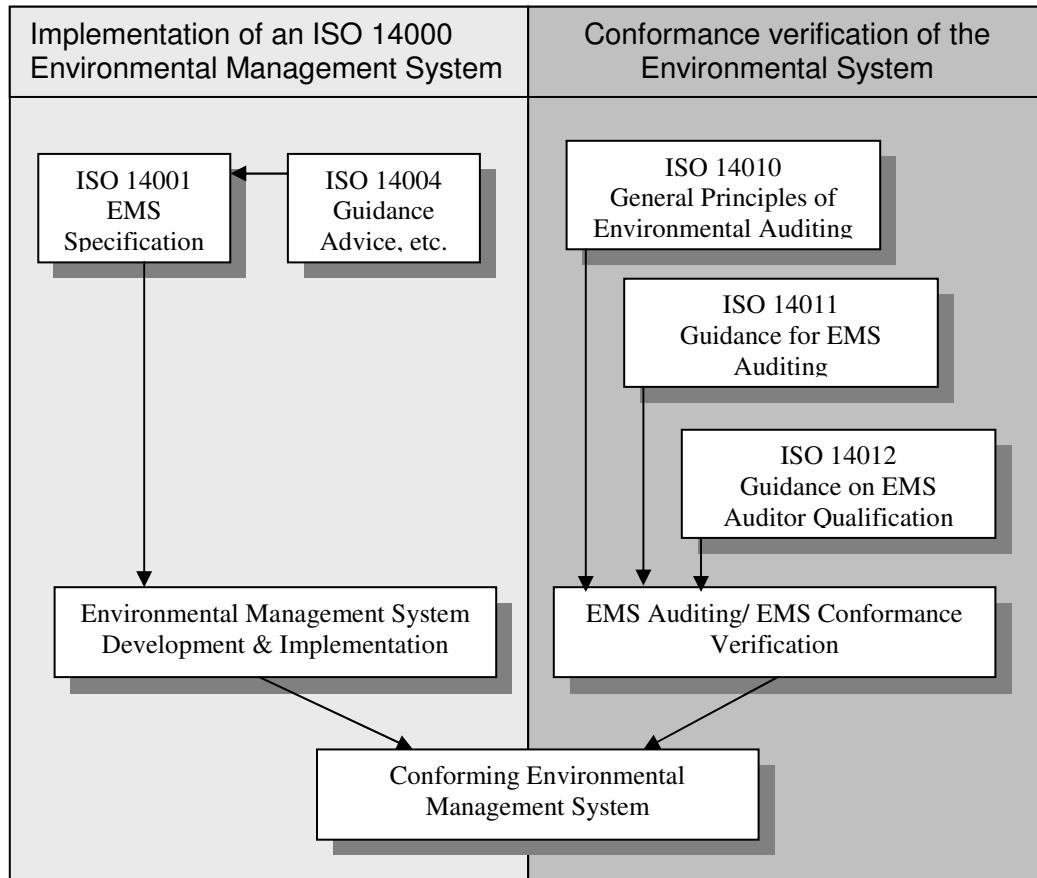


Figure 6. Interrelationship of ISO14000 Documents

Similar to the Quality Management System (QMS) implemented for ISO 9001, the ISO14001 requires implementation of an Environmental Management System (EMS) in accordance with defined internationally recognized standards (as set forth in the ISO14001 specification). The ISO14001 standard specifies requirements for establishing an environmental policy, determining environmental aspects & impacts of products/activities/services, planning environmental objectives and measurable targets, implementation & operation of programs to meet objectives & targets, checking & corrective action, and management review.

As with ISO9001, the key to a successful ISO14001 EMS is having documented procedures that are implemented and maintained in such a way that successful achievement of environmental goals commensurate with the nature and scale of our activities is promoted. In addition, the EMS must include appropriate monitoring and review to ensure effective functioning of the EMS and to identify and implement corrective measures in a timely manner. (ISO, 2002)

ISO14001 standards include the need for sites to document and make available to the public an Environmental Policy. In addition, procedures must be established for ongoing review of the environmental aspects and impacts of products, activities, and services. Based on these environmental aspects and impacts, environmental goals and objectives must be established that are consistent with the environmental policy. Programs must then be set in place to implement these activities. As with the QMS, internal Audits of the EMS must be conducted routinely to ensure that non-conformances to the system are identified and addressed. In addition, the management review process must ensure top management involvement in the assessment of the EMS, and as necessary, addressing need for changes.

The Environmental Management System (EMS) document is the central document that describes the interaction of the core elements of the system, and provides a third-party auditor with the key information necessary to understand the environmental management systems in-place at the company. Consistent with the principles of ISO14001, the Environmental Policy and Environmental

Aspects/impacts analysis, including legal and other requirements, shape the program by influencing the selection of specific measurable environmental goals, objectives, and targets.

Specific programs and/or projects must then be developed to achieve these environmental goals, objectives, and targets (in ISO14001 terms, this would be referred to as "Implementation and Operation"). The checking and corrective action elements of the system help ensure continuous improvement by addressing root causes on non-conformances. The ongoing management review of the EMS and its elements helps to ensure continuing suitability, adequacy, and effectiveness of the program. (ISO, 2002)

For many companies, conformance to ISO 14001 may become a contractual requirement of customers in both the U.S. and the European Community (EC). Also, because ISO 14000 is a continuation of the ISO 9000 Product Quality standards, it is expected that ISO 14001 will eventually become a requirement for attaining ISO 9001 re-certification. Thus, many companies are setting goals to establish environmental management systems that conform to ISO 14001 guidelines in order to remain competitive in the global marketplace. For those companies who have already obtained ISO 9001 registration and/or follow Total Quality Management (TQM) system principles, the ISO 14001 registration is a logical next step because it is very similar to ISO 9001 and the principles of TQM.

ISO 14001 is an internationally recognized standard for environmental management systems. Conformance to the standard can help companies remain

competitive in the marketplace. For many companies, both their competitors are seeking registration and their customers are beginning to demand conformance to ISO14001 guidelines. As with the ISO9001 standard, the continuous improvement requirements of the standards lead to registered companies eventually needing to require that their suppliers also comply with the ISO14001 standards. In addition, by establishing and maintaining an Environmental Management System that meets the standards established by ISO14001, companies will be implementing a strong and effective environmental management program.

Some of the benefits of implementing an Environmental Management System (EMS) in accordance with the ISO14000 standards, include: identifying areas for reduction in energy and other resource consumption, reducing environmental liability and risk, helping to maintain consistent compliance with legislative and regulatory requirements, benefiting from regulatory incentives that reward companies showing environmental leadership through certified compliance with an internationally recognized EMS standard, preventing pollution and reducing waste, responding to pressure from customers and shareholders, improving community goodwill, profiting in the market for "green" products, responding to insurance company pressure for proof of good management before pollution-incident coverage is issued, and demonstrating commitment to high-quality. (ISO, 2002)(Montabon et al, 2001) In addition to the product marketing benefits of obtaining ISO 14001 registration, the U.S. Environmental Protection Agency

(EPA) is currently considering regulatory incentives under its Common Sense Initiative (CSI) program to benefit companies certified to ISO 14001. (ISO, 2002)

The EPA is very supportive of ISO14001 stating, “the new global Environmental Management System standard is proving to be an effective tool in improving industrial environmental performance. The intent of the standard is to establish and maintain a systematic management plan designed to continually identify and reduce the environmental impacts resulting from the organization’s activities, products, and services.” (EPA, 2001) Yet the EPA does not intend to make ISO14000 a regulatory requirement, rather officials will consider a company’s efforts toward ISO14000 when imposing fines if a violation is found, likewise with related sentencing imposed by the Justice Department. Other benefits the EPA sees as a result of a company achieving ISO14001 compliance include public recognition, fewer scheduled inspections and audits in exchange for ISO compliance, faster permitting, adoption in place of compliance penalties, streamlined reporting paperwork. It may become a requirement for government suppliers/ vendors. (EPA, 2001)

A study of over 1,500 varied manufacturers found many interesting observations about the perceived impact and effectiveness of ISO14001 certification. It should be noted that only 2.5% of the respondents have actually achieved ISO14001 certification, although 20% of respondents partake in voluntary industrial or voluntary EPA environmental programs. The respondents in this study came from a variety of industries and were in a variety of managerial positions. They

had been involved in a variety of improvement programs. Generally speaking respondents perceived ISO14001 as having negative impacts on core operational metrics (i.e. lead time, cost and quality). They also do not see that ISO14001 will improve their companies' market place position of ability to sell products internationally. The study found that the closer a company is to ISO14001 certification the more favorable their opinion of the related benefits to the company. (Russo, 2001)

Companies that have attained ISO14001 certification are more likely to be large, foreign owned, ISO9000 or QS9000 certified, successfully implemented a TQM program, and effectively utilize cross-functional teams. Compared with other voluntary-based programs aimed at improving environmental performance, the evidence indicates that the ISO 14000 certification process is more effective and efficient when viewed in terms of its impact on performance. (Montabon, 2001)

The study found that for 10 of the 14 dimensions of performance, ISO 14000 is more effective than either Voluntary EPA Programs or Industrial Voluntary Environmental Programs. For 13 of the 14 dimensions, ISO 14000 is more effective than OSHA's Voluntary Prevention Program. What these results suggest is that plants actively pursuing ISO 14000 certification seem to do better on the various dimensions of performance. The reason for this improved performance is to be determined.

However, two possible explanations can be identified. The first is that ISO 14000 is process-oriented rather than output-based. As a result, when pursuing this

form of certification, firms are more likely to change the underlying processes. These changes result in more efficient processes, less waste, and less pollution. An alternative explanation lies in the requirements found in ISO 14000 for outside certification. Plants pursuing this form of certification must demonstrate to a third party that they have met the various requirements of ISO 14000. As a result, these plants are more likely to take this approach more seriously. Another explanation is that ISO14001 is systemic in nature, touching on all aspects of the business. This may serve to create a 'Green culture' that leads people to thinking Green in all that they do. (Montabon, 2001)

One study explored the cultural and organizational implications of ISO14001 and the results were rather surprising. The Moxen and Strachan (1998) study finds that ISO14001 implies a rigid top down bureaucratic approach to deploying the environmental management system. Specifically, Moxen and Strachan indicate that most of the requirements of ISO14001 are for management to establish a system of top down policies, measurements and controls, and there is little mention of other employee involvement in the program.

Furthermore, the authors caution that for environmental innovation to occur an organization must be less mechanistic and role based, and more flexible and task oriented. In other words, for true environmental innovation to occur, it is critical to improve the innovative environment of the company's culture. This logic supports the notion that Lean companies may tend more toward environmental innovation and improvement than their less lean counterparts. A

key feature of Lean companies is innovation, experimentation and continuous improvement. While the claims of Moxen and Strachan concerning the implied rigidity of ISO14001 may be exaggerated, their point that true innovation requires a supporting culture and structure is an important one. The specific difference between what they refer to as a “mechanistic role based structure” versus an “organic task based structure” is summarized in the following table. These characteristics serve as good tools for assessing “organizational readiness” toward implementing Lean or Green manufacturing systems.

Table 5. Mechanistic versus Organic Cultures

Organizational/Cultural Element	Mechanistic Management System and Role Culture	Organic Management System and Task Culture
Management of People	Favors extrinsic motivators Employees largely excluded from policy and management issues	Favors intrinsic motivators Extensive use of employee involvement schemes
Job Design Principles	Fixed and narrowly defined	Flexible, role definitions contingent on changing circumstances
Organizational Structure and Decision-making	Hierarchical, centralized decision-making Co-ordination and control rely on highly formalized and documented rules and procedures	Flat, dispersed decision-making Coordination and control based more on shared values and norms
Attitudes and Behavior	Tradition and precedent exercise powerful influence Rigid work practices, supports status quo or incremental change	Challenging and experimenting Adaptable, supports radical and fundamental change
Organizational Learning	Slow	Rapid

The EPA realizes that these tools, core values and program elements are really just parts of a complete management system for minimizing environmental waste. They also recognize that successful models already exist that can be applied to environmental improvements. They promote the use of ISO14001 as a premier model for a holistic environmental management system. But, they also recognize other existing models, based on successful quality system models that companies are happily using and may choose to use instead of the ISO14001 model. The following is a summary of these two quality based models recommended by the EPA. They are, the 7- quality model criteria approach, and the 11- quality model criteria approach.

The Seven Quality Criteria Model

The “seven quality criteria model” is based on the national Malcolm Baldrige Award model. Emphasis is on “*how*” you are working to integrate waste minimization into your organization versus “*what*” you are doing specifically. It is believed that the “*how*” emphasizes a sustainable process of improvement versus specific projects that may be short term in nature. The criteria are:

- Leadership: Top down direction is critical to any level of success, and particularly important when looking to integrate P2 across the company. In particular, there are two criteria that measure leadership.
- Strategic Planning: Leadership most often uses some form of strategic planning to guide the organization’s course. The P2 program must be important in the eyes of senior management and be so represented in the strategic planning process.
- Interested Party Involvement: No organization operates in isolation. Interested parties include the stakeholders in your P2 program. They include customers,

suppliers, regulatory agencies, non-government organizations, environmental groups, community groups, and the public at large.

- Employee Involvement: Employee involvement looks at the bottom up portion of the P2 program that is every bit as important as the top-down portion. Employees are a very important part of the P2 program, they are experts in their work areas, and are therefore best at finding P2 solutions.
- Process Management: Related to the ISO14001 EMS approach, process management focuses on how all work process are managed to facilitate the P2 program.
- Information Analysis: Information and the analysis of this information is the fuel for the P2 program. Paying attention to this criterion is the only way that clear results can be determined.
- Results: This is the most important criterion in the quality model. It moves the P2 model from anecdotal information and success stories to something that will drive all the other criteria.

It is not critical that a company do well in all 7 criteria areas. It is more important that the program addresses all 7 criteria: Breadth is more important than depth.

(EPA, 2001)

The Eleven Quality Criteria Model

The 11 Point quality model approach is very similar to the seven point quality model approach except that it adds 4 more points. The total set of elements is listed below: (EPA, 2001)

- Interested party driven pollution prevention
- Leadership
- Continual improvement and learning
- Valuing employees
- Fast response
- Efficient product, service, and process design
- Long-range view of the future
- Management by fact
- Partnership development

- Public responsibility and citizenship
- Results focus

EPA Core Waste Minimization Elements

Synthesizing these different models, the EPA developed a core list of elements that should be included in any comprehensive Green manufacturing system.

Regardless of the approach a company decides to take in minimizing environmental waste, 'all of these elements should be included in their program to assure success'. (EPA, 2001) The common elements are listed below followed by a brief description of each element:

- Planning
- Leadership
- Metrics and Goals
- Focus on results
- Information and analysis
- Process management
- Employee involvement (participation)
- Focus on interested parties

The EPA provides excellent *planning* guidelines for designing a multi-media (air, water, soil) pollution prevention program. Some EPA sources include: the pollution prevention opportunity assessment manual, the office of research and development, state and technical assistance, pollution prevention clearing house, and benchmarking studies. All pollution prevention programs should emphasize the EPA hierarchy - pollution prevention, environmentally sound recycling,

environmentally sound treatment, environmentally sound disposal. There are at least three levels of planning involved in a comprehensive Green manufacturing (waste minimization) program. They are strategic planning, formal action planning, integration and implementation planning.

Management through *leadership* must make pollution prevention part of the organization's policy and set explicit goals for reducing the volume and toxicity of waste streams. Managers must show commitment by implementing recommendations identified through assessments, evaluations and pollution prevention teams and designate a pollution prevention coordinator who is responsible for facilitating effective implementation monitoring and the evaluation of the program (i.e. facilitating self-managing pollution prevention teams). Other ways that management can motivate pollution prevention is to publicize success stories, recognize individual and collective accomplishments and train employees on waste generating impacts of their process. Further, management must lead improvement efforts both internally and externally to their organization.

There is some argument as to the preferred order of events during the *goal setting* process. The EMS approach states that Goals and objectives are established as soon as there is enough of an understanding of the systems environmental aspects to set realistic goals for improvement. Action plans are then formed to reach these goals. Under the quality model approach, goals are not set until after action plans are established. These goals are focused to each action plan and short term in nature. Short term focused goals are considered by

some to be the essence of continual improvement, as promoted by Dr. Edward Deming. (Deming, 1986)

Others believe that stretch goals such as zero waste are strong indications of the organization's never-ending commitment to continuous environmental improvement. Perhaps both schools of thought are correct. After all, the process is iterative. Clearly there is a need for different levels of goals. Long term or even unachievable goals such as zero waste, establish a strategic direction for the entire organization to rally around: A lighthouse in the distance guiding the organization through stormy seas. But, individual teams need specific near term goals to focus their action plans around. This repetition of goals setting and action plans is the process of continuous improvement. It takes an infinite number of iterations over time to reach zero waste. As to which comes first, the action plan or the goals, it's like the chicken and the egg.

It's one thing to set goals, it's quite another to make sure goals are being met by *focusing on results*. Management must stay engaged and let everyone know that these goals are important to the organization by regularly reviewing action plan status and achievement of goals. Management must also realize that improvement teams often need help from management in achieving their goals. They must be open minded and supportive of improvement efforts if goals are to be met. Regular reviews are essential as a forum for all of these points. Ideally, management will include environmental improvement status in their regular monthly operational reviews. This is a clear sign that these efforts are part of the

normal mode of business and helps to institutionalize Green thinking throughout the organization.

The types of results that should be considered in a Green manufacturing program are not just the environmental ones. There should be financial improvements as well. "All environmental results can be translated into financial results" (EPA, 2001). Money is the universal language of business, so if a company wants the support of upper management, financial savings are critical. Pollution prevention opportunities should be based on true costs of waste management and clean-up. Determining true cost requires a waste accounting system that tracks the types and amounts of waste. True costs include compliance, paperwork, reporting requirements, loss of production potential, cost of material found in the waste stream (i.e. purchase material scrap), transportation, treatment, disposal, employee exposure risk, etc.

Each organization should find the best way to account for true costs of impacting the environment. True costs of waste management should be allocated to the activities responsible for generating the waste in the first place, rather than to an amalgamated overhead. Without allocating costs, pollution prevention opportunities can be obscured by accounting practices that do not clearly identify the true cause.

Additionally, companies should express the overall environmental health and safety improvement to and from employees, customers and suppliers as important results of their Green manufacturing efforts. It is important that

everyone involved in the pollution prevention program understand the benefits of the program. This will help motivate people to get involved. Some of the obvious benefits include reducing compliance costs, reducing worker exposure, and reducing inventories of hazardous materials that reduce risk of spill/releases. Less obvious, but very important is how pollution prevention can possibly decrease future Superfund and RCRA liabilities and future tort liabilities, improving facility efficiency and product yields, enhancing organizational reputation and image. In terms of future considerations for companies, numerous states have enacted pollution prevention laws and more laws are on the drawing board. Wise companies will proactively start to budget and implement pollution prevention strategies before states edict such changes.

Proper gathering of *information and accurate analysis* is essential in guiding the organization to solving the root causes of environmental problems. The old saying “if you don’t know where you are going, any path will get your there” is an illustration of this fact. All too often companies try to implement solutions without truly understanding the problems. More time should be spent gathering relevant data and analyzing this data to understand problems before they are solved.

The term *process management* has a dual meaning regarding waste minimization. First it is important to properly manage the physical processes that generate waste. Secondly, the administrative processes that make up an environmental management system are also critical to sustained waste minimization. The EMS approach to waste minimization strongly emphasizes

that certain administrative processes are in place for environmental improvement to occur. All of the elements listed in this section, such as Goal Setting, and Employee involvement are all made up of processes and are all part of the many processes essential to waste minimization.

Higher levels of *employee involvement* translate directly to higher levels of waste reduction activity. There are opportunities in every function to prevent pollution before it occurs. Engineering can design products and processes that prevent pollution, purchasing can select materials that are less hazardous, production can improve handling and use of chemicals to prevent spills and accidents. Since few if any individuals in a manufacturing company have environmental knowledge, technical process knowledge and hands on experience of the process, the best approach is to have a cross-functional team working together toward pollution prevention. A challenge for the pollution prevention manager is to get these different groups communicating in the same language and working together, given their busy schedules.

Traditionally waste minimization programs focused inward within the manufacturing company, but focusing on all *interested parties* can yield much greater results. The EMS and quality based approaches to waste minimization particularly emphasize the importance of collaborative relationships with customers, suppliers, regulatory agencies, and other stakeholder. In recent years greater emphasis has been placed on minimizing the “life-cycle” impacts of products. During this same time, manufacturing has become more global and

horizontally integrated: Products are made of parts and sub-assemblies from all over the world. Reducing the life-cycle impacts of products requires strong collaborative relationships with all part in the extended supply/demand chain, and other stakeholders as well.

EPA Voluntary Environmental Programs

The leading environmental organization in the United States is the US EPA. Often labeled an enemy of industry only concerned with “command and control” approach to waste management, the EPA is actually very progressive in developing and supporting environmental programs that simultaneously reduce waste and operating costs. The EPA is convinced that pollution prevention is the answer to present and future environmental problems. The agency has developed several voluntary programs meant to stimulate the creative engine of industry towards devising innovative pollution prevention solutions. The following is a summary of the EPA’s existing programs that promote Green manufacturing in innovative ways. (EPA, 2001)

Source Reduction Review Project

As a short term goal, the Source Reduction Review Project SRRP ensures that source reduction measures and multi-media issues are considered as air, water, and hazardous waste standards affecting 17 industrial categories are developed. For the long term, the project tests different approaches to provide a model for the regulatory development process throughout EPA.

Pollution Prevention in Enforcement Settlement Policy

EPA negotiators are strongly encouraged to incorporate pollution prevention conditions into settlements-both criminal and civil-involving private entities, federal facilities, and municipalities.

Pollution Prevention Incentives for States

Under the state prevention grant program, EPA has awarded more than \$25 million through fiscal year 1993. These grants help states to enhance innovative and results-oriented programs, implementing multimedia prevention approaches and targeted high-risk , high-priority areas. For example, Tennessee was awarded \$300,000 for its Waste Reduction Assistance Program (WRAP).

33/50 Program

This is a voluntary initiative to reduce toxic-waste generation from industrial sources. EPA targeted 17 chemicals for reduction of 33 percent by the end of 1992 and 50 percent by the end of 1995. To date, more than 1,150 companies have signed up to participate, committing to more than 354 million pounds of reductions in toxic chemical emissions.

Green Lights Program

The first of EPA's market-driven, non-regulatory "green" programs, Green Lights encourages voluntary reductions in energy use through more efficient lighting technologies. More than 700 participants have agreed to survey their facilities

and, where possible, upgrade lighting efficiency in 90 percent of their square footage, within five years, Green Lights participants are saving more than 35,000 kilowatts annually, or \$6.9 million, in electricity costs.

Energy Star Computers

Energy Star is a voluntary partnership between EPA and the manufacturers that sell 60 percent of all desktop computers and 80 to 90 percent of all laser printers in the United States. These companies are now introducing products that automatically "power down" to save energy when not in use. Consumers will easily recognize the more efficient systems, because they will be labeled with the EPA Energy Star logo.

Design for the Environment (DfE)

DfE is a cooperative effort between EPA and industry to promote consideration of environmental impacts at the earliest stages of product design. Initial projects include designing a more environmentally conscious computer workstation and funding research into alternative synthesis of important industrial chemical pathways. A new focus of the DfE program is a joint effort with the accounting and insurance professions to integrate environmental considerations not capital budgeting and cost accounting systems.

National Industrial Competitiveness through Efficiency

National Industrial Competitiveness through Efficiency (Energy, Environment, Economics) (NICE³) is administered jointly by EPA and the US Department of Energy with matching state and industrial funds, the NICE³ grant program was provided \$4.4 million through fiscal year 1993 to support new processes and equipment that reduce high-volume wastes in industry, conserve energy and energy-intensive feed stocks, and improve industrial cost-competitiveness.

The Toxic Release Inventory

The Toxic Release Inventory (TRI) is EPA's compilation and public dissemination of the type and quantities of toxic chemicals companies are releasing to the environment, data that the companies must report annually.

Pollution-Prevention Information Clearinghouse

Pollution-Prevention Information Clearinghouse (PPIC) makes information resources available to the public and to industry to facilitate the adoption of methods, processes, and technologies for pollution prevention.

Clean Technologies Program

The Clean Technologies program (Clean-Tech) is a broad-based, applied research program focused on improving US and world-wide environmental quality, efficiency, and economic competitiveness through the development and application of innovative pollution prevention methods and clean technologies.

Under this program the EPA's Office of Research and Development creates and disseminates a wide variety of technical documents on pollution prevention. The EPA works in partnership with other agencies, universities, and industry groups to develop and evaluate cleaner technologies and processes; and provides technical assistance to various industries, particularly those composed mostly of small businesses.

Ciambrone Model

Ciambrone (1996) identified ten essential elements of a successful waste minimization program. He indicated that there had to be genuine documented management commitment for all to see. Employee's ideas must receive consideration and hopefully implementation. There had to be long-term continuity of waste minimization strategy, or as Deming said 'constancy of purpose'.(Deming, 1986) The waste minimization program has to be clear and simple. Careful initial preparation is required to assure successful implementation. The waste minimization program has to be viewed as job enhancing and not job threatening. Leadership of program implementation and maintenance has to come from line managers and not simply from the environmental group. Office personnel, factory employees and design engineers must all be involved in program design and implementation. The waste minimization program must be seen as a new way of doing business versus a fad. There must be regular and purposeful sessions, where progress is reviewed and ideas are exchanged (brainstorming).

Ciambrone (1996) offers the following best practices for reducing environmental waste. Interestingly, included in this list are distinctly Lean best practices:

- Reducing solid (non-hazardous) waste by x%/year
- Reducing hazardous waste
- Reducing the generation of priority wastes (TRI 300 chemicals)
- Reducing production scrap/rework
- Increasing the use of flexible tooling
- Reducing set-up time
- Use of environmental check list in product design
- Use of Green index rating system on materials and processes for product design and purchasing

Dillon and Fischer Model

A field research study of U.S. chemical companies concluded that higher-performing environmental companies tended to have explicit objectives, long-range planning, performance-based evaluations, proactive corporate cultures, formalized control, measurement, and reward programs. The President's Council on Environmental Quality created a framework for pollution prevention. Progress along these steps can be used as a tool to measure the success of an environmental management program. Categories of best practices for this framework include:

- Management commitment
- Quality action teams
- Training
- Determining environmental impact
- Selecting environmental projects
- Implementing improvement projects

- Measuring results
- Standardize the improvements

GEMI Model

The Global Environmental Management Initiative (GEMI) established an environmental self-assessment program based on the 16 principles from the Charter for Sustainable Development. The GEMI principles are more specific and action oriented than the original 16 principles from the Charter for Sustainable Development. These environmental best practices include: (GEMI, 2000)

- Recognize environmental management as a top corporate priority
- Integrate environmental programs into each business
- Continually improve environmental programs
- Educate employees
- Assess environmental impacts before starting projects
- Minimize the impact of products and services
- Advise customers in the safe handling of products
- Operate facilities with minimal impact
- Research the environmental impacts of operations and ways to reduce these impacts
- Change processes to prevent serious environmental harm
- Promote improved environmental activities of contractors
- Prepare for emergencies
- Transfer environmentally sound technologies
- Contribute to public education and policy development
- Foster openness with employees and the public
- Measure and report environmental performance

Responsible Care Program

Members of the Chemical Manufacturers Association (CMA) are evaluated by the Responsible Care ® program. The members of the CMA account for more than ninety percent of the basic industrial chemicals produced in the US. The Responsible Care program developed six codes of environmental management best practices on the following topics; Pollution prevention, Community awareness and emergency response, Distribution, Process safety, Employee health and safety, Product stewardship. Within the Pollution Prevention code, CMA has identified the following best practices that Green manufacturers should implement:

- Commit the organization
- Inventory wastes and releases
- Evaluate potential impacts
- Educate and listen to employees and the public
- Establish a reduction plan, goals and priorities
- Measure progress
- Communicate progress
- Integrate reduction concepts

While the Environmental Management System is an essential aspect of a company wide Green manufacturing program, it was designed for general application to all industries. As a result it cannot prescribe specific practices known to reduce environmental waste in manufacturing operations. Criticism of ISO14001 is similar to the criticism surrounding ISO9001, in that they both lack the “teeth” to truly drive improvement.

However, they create a framework of management commitment, policies and procedures that foster the implementation of best practices that do actually reduce waste, or improve quality in the case of ISO9000. So, in addition to the management system level of Green manufacturing strategy, there should be best practices that truly reduce environmental waste in the manufacturing process. Once again, manufacturers interested in these best practices have to look no further than the U.S. EPA for guidance.

EPA Guide to Pollution Prevention

In the EPA Guide to Pollution Prevention (EPA, 2001), several models of Green manufacturing best practices are offered. Companies who implement a pollution prevention (P2) program see the following improvements:

- Reduced operating costs
- Improved worker safety
- Reduced compliance costs
- Increased productivity
- Increased environmental protection
- Reduced exposure to future liability costs
- Continual environmental improvement
- Resource conservation

(EPA, 2001)

Generally speaking, the EPA P2 guide recommends some preliminary work to set the stage for the pollution prevention program. The guide indicates the importance of a management system to drive waste reduction activity to include the establishment of a vision statement, a mission statement, metrics and goals,

and the use of environmental indicators. A vision statement represents what the organization expects or the desired outcome of the pollution prevention program. A mission statement identifies what the organization needs to accomplish in the key areas that affect pollution prevention. Metrics and goals are used to set the direction of improvement and measure progress. Indicators measure progress along the way.

Another important element of a pollution prevention program is to establish a set of core values that are used as guiding principles of conduct during the implementation of the Green manufacturing system. The core set of values is specific to each company, based on the company beliefs and ethical constructs. Some examples of core values appropriate to a Green manufacturing system are as follows. (EPA, 2001)

- Interested party-driven approach: Understanding who environmental stakeholders are and what they expect from the Green manufacturing system.
- Leadership: Everyone in authority must set an example and conduct themselves and their business dealings in an environmentally conscious manner.
- Continuous improvement : The Green manufacturing system is a living system that will die without continued involvement toward the unachievable goal of zero waste.
- Valuing employees: The most important resource to any company in meeting its objectives is its people. This is no different for improving environmental quality.
- Design environmental waste reduction into products and processes: An ounce of prevention is worth a pound of cure.
- Maintain a long-range outlook: Green manufacturing takes a long term commitment. The program should not be abandoned if immediate results are not attained.
- Management by fact: Measure things accurately and let the facts guide behavior.
- Partnership development: Developing partnerships between different functional departments within the corporation and with external stakeholders is essential to efficient and continual environmental improvement.

- Corporate responsibility and citizenship: A green manufacturer is a good corporate citizen always concerned with business ethics and the protection of public health, safety and the environment.
- Fast response: Green manufacturers must always keep abreast of environmental opportunities and challenges, such as changing regulations. The ability to respond quickly to these changes keeps the company one step ahead of the competition.

(EPA, 2001)

The EPA also offers suggestion on specific tools for waste minimization.

Coincidentally, the tools they recommend are often used in TQM and Lean manufacturing programs. These tools are examples of how a Lean or Green company can apply its waste minimization tools toward reducing all forms of waste. Specifically, the EPA recommends the following:

- Provide top management support: Without management support there can be no waste minimization program. Management must set clear objectives and provide resources and active leadership.
- Process Mapping: The process map identifies in a flow chart form the stages of the process. Included in these can be inputs to the process at each stage (material, energy, hazardous solvents, etc.) and process outputs (products, and wasteful by-products).
- Determining costs of loss: It is essential to quantify the cost of waste in order to justify expenditures to minimize the waste. Several costs that should be considered include the raw material that is wasted, treatment costs, disposal costs, clean-up costs, and when possible potential liability costs.
- Selecting waste minimization opportunities: This is a process of prioritization, focusing on opportunities with the greatest opportunity for improvement. Apply the Pareto (80:20) rule.
- Encourage technology transfer: Learn from the experiences of others. Take advantage of partnerships, other facilities within the company and trade organizations to obtain new ideas for waste minimization.
- Perform periodic waste minimization assessments : Make sure that solutions are still in effect and that process changes are accounted for.
- Conduct program evaluations: Keep the Green manufacturing program alive by conducting regular reviews and refocusing the program as it evolves.

(EPA, 2001)

Design for the Environment

In addition to the waste minimization/pollution prevention models summarized above, there is a distinct body of research on the subject of environmentally conscious design, known as Design for the Environment (DFE). The premise of Design for the Environment is to design a product with minimum impact on the environment. It is during the design phase that almost all potential environmental effects of the product are determined. For example, the raw material the product requires for its manufacture is determined at this stage. The product design dictates how the product is manufactured and even the need for hazardous materials in the manufacturing process. The recyclability of the product is also determined at this stage. Product reliability that is designed into the product also determines product longevity. The functionality of the product, which determines the product's impact on the environment during its useful life is also determined at the design stage. The following Design for Environment best practices help to minimize a product's environmental impact during the design phase. (EPA, 2001)

It is important when designing a product to assure that the product is modular, meaning that it can be easily disassembled for recycling. Modularity also means that subassemblies are shared with different product, so that subassemblies can be refurbished and used in other products. Modularity also means that rather than fully replacing an item when it becomes obsolete, it is possible to simple upgrade a few of the subassemblies and keep the rest of the unit. Computers and peripherals offer great opportunities for modular design. (EPA, 2001)

Minimize the different number of materials (e.g. similar grade plastics). Specify recycled, rather than virgin materials or at least a blend. Specify materials that can be recycled. Minimize toxicity of materials, no significant toxicity should be allowed. This should include both direct (product) and indirect (process) materials. This implies both product and process design changes to include these materials. All plastic part should be marked with ISO identifying marks, size, geometry and function permitting. This helps in the sorting and recycling of these materials. (EPA, 2001)

Product should be easy to assemble and disassemble. This promotes efficient re-manufacturing and separation of materials for recycling. Any surface treatment required should be compatible to the recycling of the base product. Labeling, such as UL should be molded-in rather than using stickers, as not to degrade recycling. (EPA, 2001)

Subassemblies should be modular, making separation from the main unit easy, for repair and recycling. Parts prone to failure should be placed in accessible locations on the subassembly to facilitate repair. Should facilitate product upgrades in a modular manner rather than replacing entire unit. For example, replacing the CPU module of a computer rather than the entire mother-board or entire PC, just because a new microprocessor makes the old one obsolete. (EPA, 2001)

Progressive companies include the following tactics in their DfE programs:

- Eliminate CFC cleaning in favor of aqueous or no clean solutions
- Hazardous chemicals are replaced with more benign chemicals
- Material reduction, reuse, and recycling are all considered in the design phase
Products are designed for ease of disassembly or remanufacturing
- Generic parts are designed that are easily removed and can be reused in a variety of products (modularity)
- Improve handling and containment of chemicals to prevent evaporation or spills/leaks in production operations (EPA, 2001)

One of the major aspects of a successful DfE program is the organization assigned to this effort. No single engineering discipline contains the knowledge to achieve true Green Manufacturing, which requires evaluating the environmental impact of the entire product life cycle. This group would possess the knowledge necessary to fully account for the environmental impact of product and process in terms of present and future environmental regulations.

Environmental engineers are trained to manage waste streams. They lack knowledge of process and product design. Likewise product and process design engineers lack knowledge on environmental regulations and impact.

If these engineers are teamed together, they can design products that minimize waste and cost simultaneously. Environmental engineers can specify environmentally benign or recycled materials that design engineers can use in the product and process development; thereby preventing waste, and the associated waste management costs, from ever occurring. If done properly, management should see a direct pay back to this “concurrent engineering”

approach to Green Manufacturing. Several Green manufacturing leaders include the following aspects in their DfE programs: (EPA, 2001)

AT&T maintains a highly visible yet straightforward methodology for DfE avoiding complicated LCA analysis. They integrate EH&S into all major business considerations. Management believes that DfE provides a good cost benefit ration and is a competitive tool. Accounting practices allocate costs properly to the activity generating the waste, rather than general overhead. They use DfE to assess suppliers and alliance partners and make trade-offs as opposed to mandates to suppliers regarding green products. They blend together environmental protection and business growth.

IBM views DfE as a highly competitive tool when successfully integrated into engineering and operations. They Create DfE concept and general guidance documents at corporate level. Business units and operations are responsible for DfE deployment and impact assessment. IBM views DfE a boundary condition to product development.

Xerox's ARM (Asset Recycling Management) organization is credited with saving more than \$50 million in materials and logistics in 12 months. Thirty people are responsible for deploying ARM within design groups. ARM is a profit and loss organization. Embedding DfE activities in operations resolved conflicts between divisions and the EH&S organization.

Total Cost Accounting

One of the reasons manufacturers have been slow to adopt Green manufacturing systems is because waste management costs are often not directly associated with the cost to manufacture a product. Waste management costs are hidden in the overhead structure, making it difficult to justify savings to a specific manufacturing process by investing in clean technology. An approach known as Total Cost Accounting (TCA) is being implemented in progressive companies that directly ties waste management costs to the costs of the process and/or product producing the waste.

This fundamental change in accounting calculations is the necessary stimulus for management to recognize the costs of wasteful processes and the benefits of clean technology investment. Business decisions will revolve around a central goal of "zero waste" as an ideal philosophy for business, much like zero defects is the appropriate goal for quality. Total Cost Accounting (TCA) encompasses four elements: cost inventory, cost allocation, time horizon, and financial indicators.(EPA, 2001)

In evaluating the profitability of prevention investments, firms often exclude costs that rightfully belong in the analysis. *Cost inventory* is a method to resolve this problem. Accurate costing for prevention has obvious benefits for sound business management, but in practice it is often more complicated than it first appears. Depending on where the usage is measured the results will vary. For example, is the amount based on what was purchased? Is measured on how

many products were produced multiplied by the quantity per unit, plus a waste factor? The answer is using both techniques to get a full picture of how much of the purchased material was used.

Closely coupled with "how much" is the question, "by what". In other words, which processes or products are responsible for hazardous materials used and wastes generated. *Cost allocation* is a method to answer which processes generate the wastes. To answer this, the firm must assign figures to specific processes or products. Doing so requires a precise picture of how materials flow into, through, and out of the manufacturing process. This tracking is often referred to as "mass balance".

When business looks at a potential prevention investment, it must ask the question: How long will it take to show profitability? Proper use of *time horizons* can answer this question. Prevention investments often take time to show profits, particularly when profitability is based on such items as future liability avoidance, recurrent savings due to waste avoidance, and revenue growth owing to market development of environmentally sound products. A TCA approach takes future benefits into account by considering at least a five-year time horizon, whenever feasible.

Financial indicators for pollution prevention projects should capture all the elements discussed above. Net Present Value (NPV) meets this criteria and Internal Rate of Return (IRR). One measure that does not, though it still may be used as a project screening tool, is simple payback.

TCA helps justify pollution prevention alternatives. The EPA's Guide to Pollution Prevention and Waste Minimization (2001) helps companies identify the full cost of hazardous materials and hazardous waste management. It provides NPV, IRR, and annualized cost savings calculations for pollution prevention projects.

The manual identifies four levels of cost types:

- Usual costs - equipment, materials, labor
- Hidden costs - monitoring paper work, permit requirements
- Liability costs - future liabilities, penalties and fines
- Less tangible costs - corporate image, community relations, consumer response

Some interesting discoveries occur when Total Cost Accounting is applied.

National Association of Plastic Container Recovery - concluded that after analysis from raw material extraction through recycling to disposal PET plastics was more energy efficient than glass or aluminum containers. Another study indicated that plastic bags were far superior to paper bags. ECO balance sheet: Return on environmental investment. The eco-balance sheet is a way to integrate environmental concerns into daily decision making, transitioning from cost avoidance to environmental profitability.

Better understanding total costs and taking active steps to eliminate present and future costs of waste will help a company's competitiveness now and in the future. Progressive companies see the benefits of factoring in present and downstream environmental costs into their cost accounting systems, incentives for this approach include:

- Traditional, environmental costs had been assigned to general overhead, since they were relatively low and the cost of tracking relatively high. These allocation methods are becoming inappropriate due to decreased reporting and compliance costs and soaring environmental compliance regulations.
- Adopting proper environmental compliance practices can decrease pollutant levels and save money. Penalties and law suits can be more costly for those not complying with federal and state regulations.
- Correctly tracing and allocating environmental costs involves properly identifying cost drivers, which imply cause-and-effect relationships between assigned costs and allocation bases, and identifying nonlinear cost relationships to avoid distorted cost estimates.
- Strategies for managing environmental costs involve giving managers appropriate incentives for environmental compliance costs, because successful financing, sound investment decisions, and competitive advantage primarily rely on the accuracy of data supplied by management.

(EPA, 2001)

Scallon and Sten Model

Now that an overview of Green manufacturing model components is complete, it is important to understand the process of Green manufacturing system diffusion and the correlation between system components. Lean manufacturing studies indicated that companies implement Lean best practices starting with management commitment, production operations, support functions and then outward to the extended supply chain. Is this true with Green manufacturing best practice deployment as well? The following study sheds light on the process of Green best practice deployment for a small group of known Green companies in the pacific northwest of the USA. The two studies that follow focus more on the interrelationship of Green manufacturing system components.

A study performed by Scallon and Sten (1997) looked at the environmental behavior of 36 companies in the Pacific Northwest of the United States. The companies were selected based on their involvement in voluntary environmental

programs, and reputation as environmental leaders in their industry. Information was gathered by five people (2+ person teams) doing face to face interviews, 45 min. + each, with at least one person from the company. Information is of a qualitative nature. Companies were grouped by size: Large companies had over \$1 billion in sales. Medium sized companies had sales greater than \$75 million. Small companies had less than \$75million in sales or less than 1,000 employees. Companies were grouped into four categories of environmental behavior (Compliance, Alignment , Expansion, and Integration) and are described below.

Compliance Group

The Compliance group, consisting of six companies, focused on maintaining a strong compliance record. They try to keep up and comply with regulations. They are primarily reactive, either to regulations or to specific customer requirements. They participate in environmental activities that are either required by law or are least-cost alternatives. They have the primary motivation to avoid problems, stay out of trouble, or stay in business. Attitudes reflective of this group are: "Any other way would have required more changes; Our recycling program grew out of a disposal problem, We are expecting a wake-up call, a big law suit." (Scallon and Sten, 1997)

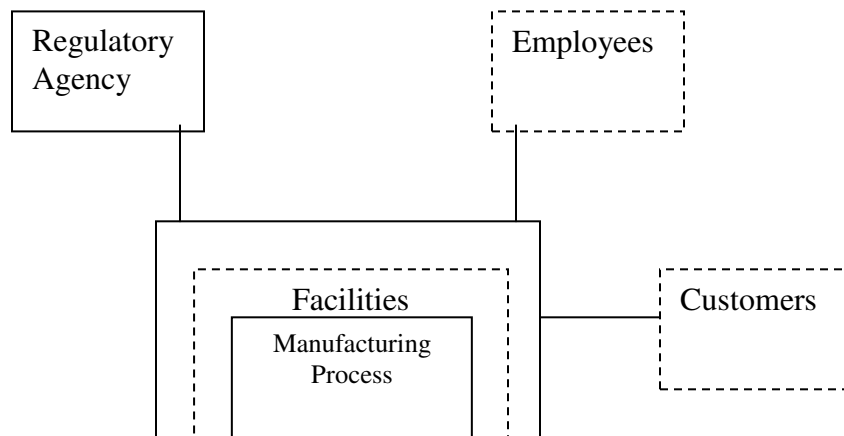


Figure 7. Compliance Group

Environmental activity is confined to the manufacturing process and regulations that influence them. Recycling programs are the primary facilities-related activities, and perhaps a carpool or similar employee program is in place. The only customer specific areas addressed are those dictated by the customer.

(Scallon and Sten, 1997)

Alignment Group

The Alignment group, consisting of 10 companies, recognizes that environmental issues and trends can open up new cost savings areas and market opportunities. These companies are beginning to align their business objectives with their environmental objectives. The idea that being environmentally responsible is the right thing to do also comes to light in Group II. However, behavior in relation to environmental issues is still driven more from a desire to minimize risks and avoid compliance problems. By setting their own targets, these companies see

that they can minimize planning risk and their vulnerability to changing regulations within their planning horizon. These companies:

- Try to keep ahead of regulations through early compliance and often participate in voluntary compliance programs.
- Primarily address environmental issues that relate to or that are extensions of compliance issues, business survival issues or changing market conditions.
- Recognize that addressing environmental issues can be profitable, yet are generally unwilling to make significant investments in non-mandatory environmental activities that do not have expected measurable returns.
- Have motivations that include a desire to be ahead of compliance issues, potential economic benefits, and being responsive to changes in market demand.

(Scallon and Sten, 1997)

Attitudes reflective of this group are: Compliance is the focus unless savings are involved. Most environmental activities are performed because they are driven by compliance forces. They recognize the value added component of environmental improvement, but compliance has been the main thing. These companies are sensitive to the people who work here and related environmental health and safety concerns, so they try to go beyond compliance. (Scallon and Sten, 1997)

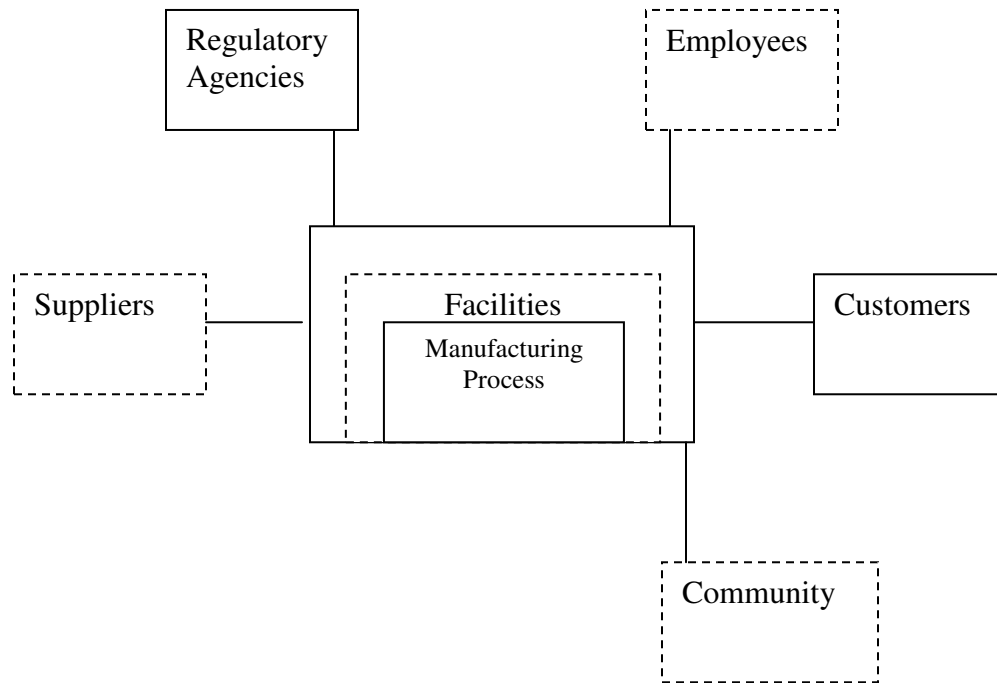


Figure 8. Alignment Group

Companies in this group recognize changing customer demand and the related potential opportunities, and new or redesigned products and services are being developed. Some community-related activities such as highway clean-up programs may be in place, and new cost effective recycling service suppliers may be identified to replace costly hazardous material disposal. (Scallon and Sten, 1997)

Expansion Group

The Expansion group, consisting of 14 companies, is proactive in nature, and search for opportunities to improve environmental improvement. In other words, an environmental ethic takes precedent over compliance concerns. Companies

in this group see environment and even regulations as opportunities. Doing the right thing environmentally is expected behavior. Seeking opportunities for environmentally conscious behavior is performed throughout the organization and enterprise (outside the company). Environmental issues take a higher priority and are addressed at a high level in the organization. These companies involve many key stakeholders in their environmental strategy. In general these companies:

- Work to influence regulations in a positive way
- Are characterized by the development and implementation of programs that go beyond areas of compliance, survival and market changes.
- Have a wider range of environmental activities, which include programs that involve customers, suppliers, and the community
- Address facilities-related environmental issues in addition to manufacturing process issues.
- Often have comprehensive waste minimization or pollution prevention programs
- Have elements of an environmental management system, and a willingness to experiment continually (a.k.a. continuous improvement)

(Scallan and Sten, 1997)

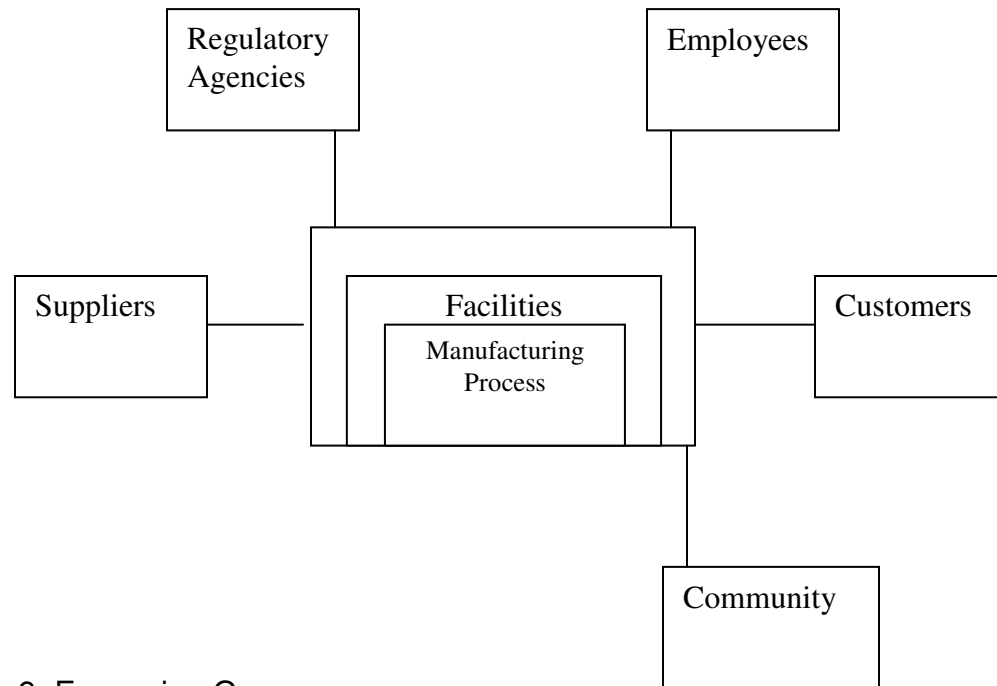


Figure 9. Expansion Group

A greater emphasis is put on employee and supplier oriented initiatives, including the use of employee 'green teams' to address environmental problems and the creation of supplier programs to re-evaluate product inputs and reduce or redesign packaging. Product take-back programs are a good example. Community involvement initiatives and facilities-related energy-efficiency programs are also significant and well established components of the environmental efforts of this group. Elements of an environmental management system are in place. (Scallon and Sten, 1997)

Integration Group

Companies in the Integration group have developed an organization culture and internalized the perception that environmental issues provide opportunities.

Some companies in this category developed due to a strong environmental ethic. Others have developed environmental programs due to a respect to changing political, market and economic concerns about the environment. Either way, decisions are based on environmental opportunities and upholding an environmental ethic. This group has begun to institutionalize its expanded definition of the role of environmental issues in the organization. These companies:

- See the value of actively addressing environmental issues as an integral part of the operation of their business
- Approach environmental issues strategically
- Have a structure in place to generate new project ideas, address different area of concern, and look at issues of interest to a wide range of relevant constituencies
- Recognize the role of employee involvement and corporate culture in being an environmentally-responsive company
- Recognize the benefits of environmental activities, but do not require individual environmental initiatives to provide a return or break even

(Scallon and Sten, 1997)

Attitudes reflective of this group are: The nature of our business instills in us the need to protect the environment. It is up to us to use rigor and common sense to measure what is really at stake. Environment is integral to our business and our environmental activities emanate from our value system. We are working to incorporate an environmental ethic into all decision-making and new products and product lines. (Scallon and Sten, 1997)

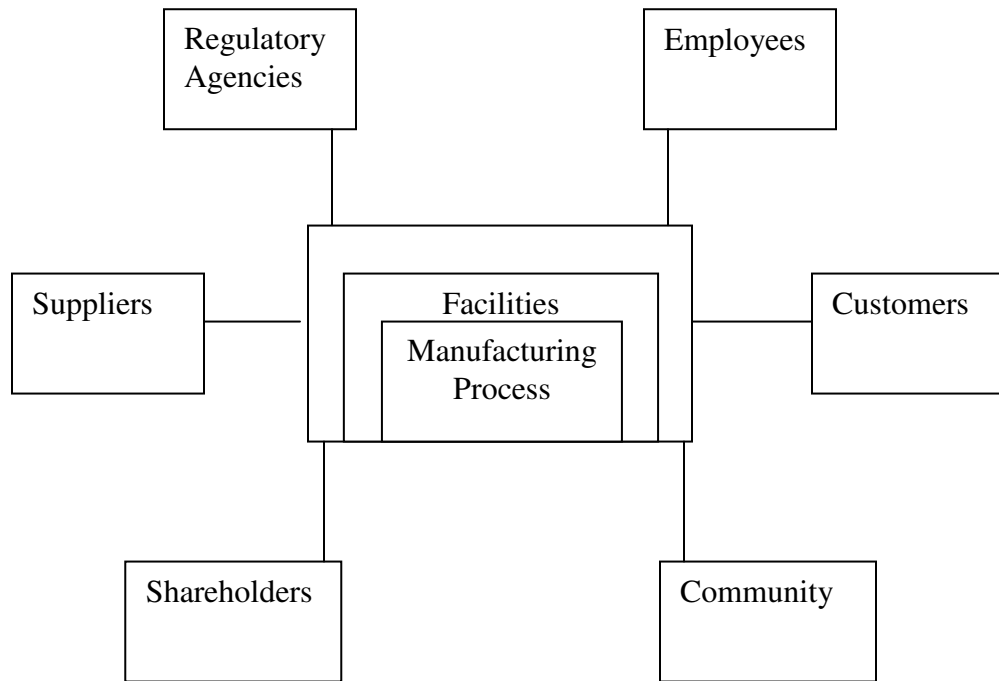


Figure 10. Integration Group

These companies take their programs a step further by addressing the concerns of shareholders, which often involves the publication of environmental progress reports. They institute systems and strategies that ensure environmental concerns are integrated into all aspects of the company's business. (Scallon and Sten, 1997)

The Scallon and Sten study shows that as a company evolves from Compliance to Integration the scope of environmental activities expands to reach a broader group of stakeholders. Similar results were found in the Panizzolo (1998) study of Lean manufacturers whereby companies typically began Lean implementation on the factory floor and then expanded outward to support functions and ultimately to customers and suppliers. Therefore, research indicates that, as companies' appetites for reducing waste increases, they seek out untapped

opportunities both internally and externally. This logic supports the hypothesis submitted in this study that as a company becomes Leaner it will seek out new opportunities to reduce waste, which should lead it to implementing Green best practices. And, as a company becomes Greener it will also seek out new opportunities to reduce waste, which will lead them to implementing Lean best practices. Thus, we should see a correlation between the extent to which a company implements Lean and Green manufacturing best practices. (Scallon and Sten, 1997)

The Russo Model

Michael Russo from The University of Oregon observed a rapid increase in annual ISO14001 registrations over the past several years. Curious as to what this might mean in terms of improved environmental performance, he conducted a literature review. He realized that there had been no thorough analysis of the environmental impact of ISO14001 on emissions. He then posed the research question: Does ISO14001 certification actually lead to environmental improvements? He determined that this was a very important question given the recent acceleration in ISO14001 certification worldwide. If ISO14001 has a positive impact on environmental performance, then this would be magnified by the number of firms becoming registered.

The main hypothesis for the Russo study was: Facilities that receive ISO 14001 registration will experience environmental performance improvements (as measured by the EPA's Toxic Release Inventory (TRI) data). The findings for the Russo study include:

- For the entire sample, the presence of an EMS (ISO14001 or otherwise) was a significant predictor of improved toxic emissions performance.
- Within the sample of facilities with emissions above TRI reporting thresholds, ISO 14001 registration significantly reduced subsequent toxic emissions.

The Russo study provides strong evidence that there is a correlation between a Green Management System and Green results. It indicates when management formally commits itself and the organization to reduce environmental waste, it happens. If it can be shown that as a manufacturing plant's level Leanness correlates positively to its certification to ISO14001, then it can be logically inferred from Russo's study that the plant is also experiencing reduced TRI emissions. The studies methodology is summarized below and a more complete description is in Appendix A.

Russo Methodology

Sample:

The study explored the adoption and impact of ISO 14001 within a sample of electronics plants, broadly defined. The plant, or facility, was chosen as the unit of analysis for two reasons. First, it is facilities—not firms—that are registered under ISO 14001. The ISO 14001 registration process was designed specifically to operate at this level, as it was patterned after the ISO 9000 quality standards (Tabor, Stanwick, and Uzumeri, 1996). Second, data within the Toxic Release Inventory is organized at the plant level, and aggregation beyond that level creates imprecision. In order to balance the need for a viable sample size with comparable industry environments, six segments of the electronics industry were selected for analysis: SIC 3571 (Electronic computers), SIC 3651 (Household audio and video

equipment), SIC 3661 (Telephone and telegraph equipment, SIC 3671 (Electronic tubes), SIC 3672 (Printed circuit boards), and SIC 3674 (Semiconductors and related devices). Thus, there is a high degree of commonality to the sample, responding to criticism of studies with samples that are too dispersed (Griffin and Mahon, 1997). The numbers of observations for the two studies are shown in Table 1. I used as the population all facilities in these segments where manufacturing took place and which employed at least 100 persons. Data furnished by Dun and Bradstreet listed 1104 such establishments.

A university survey research center randomly selected and contacted facilities from the set of 1104 facilities in early 2000. A total sample of 316 facilities provided interview data. Given that 95 of the original 1104 sites were not actually manufacturing sites or were used for other lines of business, the interviewed sample consisted of 31.3% of the population. All facilities were contacted multiple times, and the main reason for non-response was inability to get to the respondent either due to absence or having an answering machine respond to all interview attempts. Refusals by respondents were a relatively minor occurrence, at roughly 5% of non-respondents. When contacting firms, in order to avoid biases, interviewers did not leave phone messages, as this might have affected the chance of a return phone call. The level of success we enjoyed might be due to the relative lack of knowledge about ISO 14001, the desire of environmental managers to receive copies of the results of this study, or a desire to improve the network among environmental professionals. In early 2001, a second wave of surveys was sent to firms that had not yet registered to ISO 14001 to ascertain whether or not they had done so.

Of the 316 facilities that were contacted, a number was dropped from each analysis because the interviewee did not provide information on all variables that were used in analyses. In addition, for the study of toxic releases, an additional 196 facilities had to be handled differently because they did not produce enough toxic emissions for any effluent to report to the Environmental Protection Agency (This raises the issue of selection bias, with which is explicitly addressed below). Table 1 provides a summary of the available facilities and observations for the adoption study and emissions study, organized by Standard Industrial Classification area.

Study Period. I used the years 1996 through 2000 for the study of ISO 14001 adoptions. Although the ISO 14001 standards were finalized in late 1996, their general nature was well known prior to that point, and in fact several respondents claimed to have “registered” earlier in 1996. This is feasible, since the drafts of ISO 14001 were available by 1995 (Epstein, 1995). For the emissions study, as toxic emissions data is only available through 1999, that year is the last one used in that analysis.

Melnyk, Stroufe, Calantone Model

A study conducted by Melnyk, Stoufe and Calantone, in 2002 explored the effect Environmental Management Systems (especially ISO14001 EMS standard) have

on the implementation of “environmental options” (a.k.a. Green Waste Reducing Techniques) and, interestingly enough, the effect of a formal EMS on “Operations performance” described as Lead time, Quality, and Cost (a.k.a. Lean Results). This is an interesting study in that it looks directly at two of the main correlations in the research model, the correlation between GMS and GWRT, and GMS and LR. The methodology developed for this study is very applicable to our research model as well. For completeness, relevant excerpts from the Melnyk et. al. study are included below:

Melnyk Abstract

There has been an increase in interest towards corporate activities aimed at reducing or eliminating the waste created during the production, use and/or disposal of the firm's products. Prior research has focused on the need for such activities, while current research tries to identify those components that encourage or discourage such activities. As a result of the introduction of ISO 14001, attention has turned to corporate environmental management systems (EMS). The underlying assumption is that such a system is critical to a firm's ability to reduce waste and pollution while simultaneously improving overall performance. This study evaluates this assumption. Drawing on data provided by survey of North American managers, their attitudes toward EMS and ISO 14001, this study assesses the relative effects of having a formal but uncertified EMS perceive impacts well beyond pollution abatement and see a critical positive impact on many dimensions of operations performance. The results also show that firms having gone through EMS certification experience greater impact on performance than do firms that have not certified their EMS. Additionally, experience with these systems overtime has a greater impact on the selection and use of environmental options. These results demonstrate the need for further investigation into EMS, the environmental options a firm chooses, and the direct and indirect relationships between these systems and performance. (Melnyk et. al., 2003)

Melnyk Hypotheses

Hypothesis 1: Performance is lowest when EMS is not present, intermediate when EMS is present but not ISO14001 certified, highest when EMS is present and ISO 14001 certified.

Hypothesis 2: Use of environmental options are lowest when a formal EMS is not present, intermediate when a formal EMS is present but not ISO 14001 certified, and highest when a formal EMS is present and ISO 14001 certified.

Melnyk Methodology

A survey was used to collect data for this study. The survey gathered data on the environmental activities, the state of the firms EMS, and the effects on environmental and corporate performance. Mailing lists of 5000 names each were obtained from the National Association of Purchasing Management, American Production and Inventory Society, and one anonymous group, with duplications eliminated. The organizations were asked to specifically provide names of managers who worked in manufacturing (SIC code range 20-39). The usable responses totaled 1510, for response rate of 10.35%.

Independent variables:

EMS: State of the EMS

SALES: To determine resources available to the firm to either help implement a formal EMS and/or to help implement Environmental options.

YEARS: Captures the age of the EMS

PUBLIC: Company is either public traded or privately owned

Controls:

SIC Codes: To ensure that respondents were manufacturing firms.

Table 6. Melnyk et al Statistics

INDEPENDENT VARIABLE	LEVEL	MEANING	NUMBER	PERCENTAGE
EMS	1	No formal EMS	591	50.9
EMS	2	Formal EMS	475	40.9
EMS	3	ISO 14001 Certified	96	8.3
SALES	1	First Quartile Sales	335	30.9
SALES	2	Second Quartile Sales	256	23.6
SALES	3	Third Quartile Sales	254	23.4
SALES	4	Forth Quartile Sales	240	22.1
PUBLIC	0	Privately held	628	51.4
PUBLIC	1	Publicly held	594	48.6
YEARS		Continuous	1055	100

Table 6. (Continued)

DEPENDENT VARIABLE	LABEL	N	MEAN	S.D.
Environmental activities within your plant have:				
Significantly reduced overall costs	ACTCOST	1142	3.35	2.57
Significantly reduced lead times	ACTLT	1143	2.71	2.28
Significantly improved product quality	ACTQUAL	1144	3.24	2.53
Significantly improved its position in the marketplace	ACTPOS	1140	3.48	2.70
Helped enhance reputation of company	ACTREP	1144	4.85	3.09
Helped company design/develop better products	ACTPRODS	1144	3.60	2.77
Significantly reduced waste within production process	ACTWPROD	1144	4.73	2.99
Significantly reduced waste in equipment selection	ACTWEQIP	1133	4.02	2.79
Had benefits that outweighed any cost incurred	ACTBENE	1138	4.21	2.83
Improved sales opportunities internationally	ACTINTER	1133	3.73	2.89
To what extent are the following <u>environmental options</u> considered in your plant:				
Product redesign	OPTPROD	1163	4.99	3.07
Process redesign	OPTPROC	1166	5.95	2.91
Disassembly	OPTDIS	1155	4.03	3.02
Substitution	OPTSUB	1163	6.02	3.05
Reduce	OPTREDUC	1160	5.82	3.03
Recycle	OPTRECYC	1165	5.48	3.19
Rebuild	OPTREBLD	1153	4.80	3.21
Remanufacture	OPTREMAN	1148	4.16	3.12
Consume Internally	OPTCONSM	1163	3.66	2.99
Prolong Use	OPTPROLN	1154	5.01	3.98
Returnable Packaging	OPTREPCK	1162	5.81	3.23
Spread risks	OPTSPRED	1153	4.44	2.89
Create a market for waste products	OPTCREAT	1156	4.24	3.07
Waste segregation	OPTSEG	1161	5.83	3.05
Relocation	OPTRELOC	1153	3.30	2.85
Alliances	OPTALL	1154	4.96	3.05

Melnyk Findings

Regarding hypothesis I, the study indicates that corporate performance is strongly affected by the presence of a formal EMS and strongly influenced by a formal ISO14001 certified EMS. The significant variables include ACTCOST, ACTLT, ACPOS, ACTREP, ACTPRODS, ACTBENE, and ACTINTER. One explanation of these findings supported by (Russo and Fouts, 1997) is that the EMS provides firms with specialized information of critical functions. These systems and functions are necessary for personnel to reduce pollution and improve overall performance. Without an EMS the firm may have no other method of obtaining this information, and therefore is oblivious to the opportunities to reduce environmental waste. Also, the EMS helps to publicize throughout the company efforts to reduce pollution and the effects on operating performance, through its formal review process. In this way an EMS serves as a “clearinghouse” of environmental waste reducing efforts of the firm, promoting awareness of environmental activities.

Regarding hypothesis II, For the option variables, the overall model was significant for every environmentally dependent variable. Furthermore, EMS2 and EMS3 were again found to have positive effect and significant on the use of all 16 options. Additionally, the differences between the two stages of a formal EMS (EMS2 – EMS3) was significant in the use of only 6 of the 16 options. (Melnyk et. al., 2003)

Lean and Green Manufacturing Studies and Models

Introduction

A small number of scholarly studies have investigated the relationship between Lean and Green manufacturing systems (Florida, 1996; Rothenberg, 2001; King, Lenox, 2001; EPA, 2003). These studies show a positive relationship between Lean and Green. The Rothenberg study shows that Lean companies have better environmental performance and embrace environmental waste minimization more so than non-lean companies. The Florida study identified some common best practices between Lean and Green management systems (e.g. management commitment, teams, new process technology, innovative product design, and supply chain management). The King, Lenox study finds that companies with low inventories of hazardous materials and who are ISO9001 certified have lower toxic emissions than companies with higher inventories and are not ISO9001 certified. Each of these studies shows correlation between some elements of a Green manufacturing system and some aspects of a Lean manufacturing system.

The Florida study (1996) found that progressive companies applied advanced management practices (e.g. management commitment, teams, new process technology, innovative product design, supply chain management) toward

minimizing environmental waste. Dr. Florida indicated that these techniques are associated with both Lean and Green manufacturing systems. “Advanced manufacturing facilities, such as those organized under the principles of lean production, draw on the same underlying principles – a dedication to productivity improvement, quality, cost reduction, and continuous improvement, and technology innovation – that underlie environmental innovation.” (Florida, 1996)

The Rothenberg study (2001) focused on the automotive industry, known for its leadership in Lean manufacturing implementation. The study shows that Lean manufacturers are more energy efficient than non-lean manufacturers. The study did not show significant reductions in emissions in Lean companies, which may in part be due to the fact that Lean companies tend to focus on source reduction rather than end-of-pipe environmental solutions. This approach is consistent with the Lean philosophy of eliminating non-value added activities and stopping problems at the source.

The King and Lenox study (2001) finds that ISO 9000 (International certification for Total Quality Management Systems) certified manufacturers with low inventories of hazardous materials have lower emissions of toxic chemicals. It should be noted that ISO 9000 is not generally considered a Lean manufacturing best practice, although there is a great deal of synergy between Total Quality Management (TQM) and Lean manufacturing.

The EPA study (2003) showed how Lean has direct Green benefits as a bi-product of efficiency gains. But the study fell short of showing that Lean led to

commitment to a Green manufacturing system that leads to sustained and broad based environmental improvement. Russo (2001) showed that committing to ISO14001 had a strong relationship to environmental improvement (TRI emissions).

The Florida Study

A study conducted by Dr. Richard Florida of Carnegie Mellon University explored the relationship between advanced manufacturing practices (e.g. Lean manufacturing) and environmental performance. The research effort included a combination of survey research, phone interviews, and field research consisting of factory visits and on-site personal interviews. The hypothesis this study set out to prove was “that firms that are innovative and adopt advanced manufacturing practices can simultaneously realize improvements in productivity and environmental performance. In other words, environmental improvements to some extent flow from broader corporate efforts to innovate and implement new and more efficient manufacturing systems and practices.” This is similar to the findings of Rothenberg who showed that Lean companies are more resource and energy efficient.

The Dr. Florida study defined the elements of Lean manufacturing as a blend of technology and organizational changes: specifically, self-directed work teams, worker rotation, continuous process improvement, supply chain management – close relations across the production chain. (Womack, 1996). The study explored the application of teams, continuous improvement, supply chain

management, management commitment and investment to improving environmental performance. Essentially the study showed that best practices commonly used in Lean manufacturing strategies are also used in Green manufacturing strategies, suggesting synergy between strategies. Specifically, the following questions were asked of respondents.

- How important is pollution prevention is to overall corporate performance?
- Are you pursuing zero emissions manufacturing?
- What percent of capital expenditures are devoted to pollution prevention?
- What are the main components of your pollution prevention strategy?
- What production process improvements were made to improve environmental performance?
- What emission level reduction resulted from waste minimization efforts?
- Rank the effect certain factors have on your corporate environmental strategies on a scale 1-4.
- Who is most important in pollution prevention?

The Florida study shows a combination of organizational practices and advanced technology into a system of waste minimization is more effective than a singular approach. The cluster analysis included key measures from the survey as well as data on firm size, sales, age, and industry obtained from Dun and Bradstreet.

Four distinct clusters of advanced-environmental practices were established that are described as follows:

Cluster 1 companies:

- Rate pollution performance as very important to corporate performance
- Represent the largest sample of companies from the study n=61 or 35%
- Are relatively large 48% over \$2 Billion, only 15% under \$500k in sales
- Exhibit high rates of adoption of technical and organizational solutions (i.e. source reduction, recycling, process technology, TQEM)
- Integrate their pollution prevention initiatives across the entire industrial chain.
- Rate productivity and technology as key drivers of their environmental strategy.

- Devote a relatively high level of capital expenditures to pollution prevention.
- Significantly reduce emissions.

Cluster 2 companies:

- Rate pollution prevention as relatively important
- Devote a relatively high level of capital expenditures to pollution prevention
- Report a high level of emission reduction
- Low adoption rate of pollution prevention technology
- Less likely than cluster one companies to adopt organizational approaches to pollution prevention such as TQEM – EI
- Low integration rate of pollution prevention efforts across the supply chain

Cluster 3 companies:

- Consider pollution prevention as of moderate importance to corporate performance
- Readily adopt new production process technology, recycling and source reduction
- Moderately adopt organizational innovations such as TQEM, and worker involvement
- Moderately adopt supply chain best practices
- Do not rate productivity improvement or technology as major drivers of their pollution prevention programs
- Dedicate moderate levels of capital expenditures to pollution prevention resulting in slow rates of emission reduction

Cluster 4 companies:

- Rate pollution prevention as relatively unimportant to corporate performance
- Exhibit low levels of organizational and technological efforts for pollution prevention
- Are mostly smaller firms
- Dedicate moderate level of capital expenditures to pollution prevention resulting in slow rates of emission reduction
- Exhibit little adoption of technology or organizational approaches directed toward pollution prevention.

The Florida study found that dependent relationships between manufacturers and suppliers leads to transferring best practices between supply chain partners, including environmentally conscious practices. Traditionally manufacturers used their supply chains as a means of outsourcing hazardous operations to make their own environmental performance at the cost of the suppliers. More recently collaborative efforts seek to improve environmental performance throughout the

supply chain. Some operational improvements in this area also have environmental benefits. Just-in-time deliveries reduce both inventory and waste. Pressure to continuously improve quality and cost performance provides incentive to reduce waste. Co-involvement in product design provides opportunities to design products and processes that are more efficient and environmentally benign.

The Florida study found the following specific examples of supplier involvement in improving environmental performance.

- Motorola proactively drives pollution prevention efforts with its suppliers.
- IBM worked with suppliers to transfer CFC based cleaning of circuit cards to aqueous based cleaning.
- Scott Paper and Safety Kleen worked with suppliers to eliminate toxic chemicals through recycling and process changes.
- Amko Plastics developed task teams with suppliers to develop water based inks or printing plastic films (24).
- Rayovac established an environmental audit and ranking system for its suppliers and worked with first tier suppliers to diffuse pollution prevention techniques throughout the supply chain.
- As part of Sony's efforts to reduce cost and waste, the company worked with suppliers to completely recycle all scraps thereby reducing environmental waste. The efforts to redesign packaging to lower cost led to using less material and lowered solid waste levels.
- Sony also reduced paint costs by going to water based paints, and lowered hazardous materials usage as well.

Dr. Florida found that progressive companies used advanced techniques to reduce environmental wastes. These techniques include the use of teams, technology investment, process improvement, involvement of suppliers and customers, pursuit of zero waste, or at least aggressive goals for waste minimization, involvement of all types of employees (i.e. executives, engineers,

workers, consultants, suppliers, and customers). These best practices are important elements of both Lean and Green manufacturing strategies.

The study does not indicate if these best practices are also applied to Lean manufacturing wastes. What we don't know is if the companies apply these best practices to reducing Lean wastes or simply began a Green manufacturing program for other reasons. In other words, did these progressive best practices originate as part of a Lean manufacturing program? Or, have these best practices grown out of a Green manufacturing program and spread over to addressing Lean wastes? This study only asks if these best practices are applied to reducing environmental wastes.

The Rothenberg Study

This study looked at the effect of Lean practices (independent variables) on three environmental metrics/performance measures (Dependent variables) in the automotive industry. Sandra Rothenberg performed a quantitative analysis of data from a Green and a Lean survey, the Environmental Practice Survey (EPS) and the Work Practice Survey (WPS), respectively. The EPS is an instrument to attain a variety of quantitative measures of plant environmental performance and management. From this survey, three environmental performance measures were used in the Rothenberg study as dependent variables. Air pollution was measured by plant level emissions of volatile organic compounds (VOCs) in kg/vehicle. Resource efficiency was measured by water use per vehicle

(m³/vehicle) and energy use per vehicle (MMBTU/vehicle). The metrics were averaged over two years.

The Work Practice Survey (WPS) provided two Lean independent variables: plant productivity and Lean management index. Plant productivity was measured as labor hours per car, lower labor hours per vehicle translates to higher productivity. The Lean index is comprised of three bundle variables, the use of buffers, work systems, and human resource management policies. The 'use of buffers' variable measures the degree to which production operations are buffered against potential disruption. It is a combination of repair area size, inventory policy (days of parts and frequency of delivery) and the size of the paint-assembly buffer. The 'Work systems' variable measures the work structures and policies that govern production activity on the shop floor and influence the skill acquisition and development of production workers. It is a combination of percent of workforce in teams, percent of work force in employee involvement groups, number of employee suggestions, amount of job rotation, and decentralization of quality responsibility. 'Human resource management practices' measures organization-wide policies that govern the relationship between management and employees. It is the combination of recruitment selectivity, training for experienced employees, contingent compensation, and status differentiation.

Both surveys, the WPS and the EPS, were conducted on the same 32 automobile assembly plants (7 in Japan, 25 in North America). One plant was

ruled out due to a unique painting process. The Rothenberg study found that Lean companies use less water and energy than their less Lean counter parts. Energy reduction was more pronounced due to the fact that energy is readily perceived as costly and may be less capital intensive to reduce than water usage. However, Lean plants tend to have slightly higher emissions of VOCs. This results from the fact that Lean companies try to exclusively use source reduction to minimize environmental waste. Whereby, traditional manufacturers use end-of-pipe containment devices such as scrubbers. While end-of-pipe solutions may reduce the amount of waste emitted at the point source, they do not reduce the amount of waste itself, rather they simply transfer it to a different media (i.e. scrubbers transfer air-born VOC waste into hazardous solid waste).

In addition to performing quantitative analysis of survey data, the Rothenberg study also performed several case studies on particular automotive manufacturers. The case studies suggested two primary ways in which Lean production benefits Green production. Lean plants have a 'waste reduction ethic' and are better organized to identify waste in the process. For example, Rothenberg found that Lean plants had a high level of employee participation in energy reduction activity. Here the Lean best practice of employee involvement is applied to the Green objective of lowering energy consumption. The study also found since operators were trained in charting, graphing and statistical analysis of production data, they were better able to identify and implement environmental improvements. Third, in a Lean manufacturing environment,

employees are continually challenged to innovate and experiment with process improvement ideas.

There are several examples in the automotive case studies from Rothenberg where the experimentation afforded to engineers in lean plants, even if it meant halting production, was critical to innovative solutions that improved environmental performance. In contrast, engineers in traditional mass production automotive plants were frustrated because they were never given time to experiment for fear it would slow down production. It seems from this anecdotal information gathered in the case studies that the quantitative analysis would show a striking difference in the environmental performance between Lean and non-lean plants. However, Rothenberg found marginal improvements in the areas of water and energy use amongst Lean plants and actually higher VOC emissions by Lean plants.

Rothenberg admits that the small sample size may have something to do with this, and the fact that Lean plants are probably reluctant to implement end-of-pipe solutions, which would account for higher VOC emissions. In one of the case studies, an environmental manager from a Japanese automotive transplant in North America stated, “instead of asking ‘how much end-of-pipe technology should we add?’ [we] put those resources into increasing efficiency and wait until regulation forces the add on controls.”

Although Lean companies primarily target the seven ILean wastes (defects, over-production, transport, waiting, inventory, motion and excess-processing), waste

is waste. The waste identification and elimination methods used on these seven wastes may spill over to environmental wastes. Lean manufacturing strives to eliminate all non-value added activities; environmental waste and the efforts to manage it certainly fit these criteria. However, this theory was not validated in the Rothenberg study. Rothenberg (2001) showed that Lean companies tended to have improved environmental performance, but did not indicate whether that was because Lean manufacturers are simply more resource efficient or if they actually implement Green manufacturing best practices.

The King, Lenox Study

King and Lenox believe that Lean and Green are complementary. For example, 'good housekeeping' or 5S practices associated with Lean manufacturing have led to the reduction of spills and other forms of environmental waste (Florida 1996, Hart 1997, King, Lenox 2001). They attempted to prove this by showing empirically that Lean leads to pollution prevention, reduces barriers to implementing environmental waste minimization solutions, and helps to identify the costs of environmental waste reduction opportunities. Thus, Lean manufacturing reduces the marginal costs of Green manufacturing due to shared practices and complementary attributes.

The empirical study combined several large databases of U.S. manufacturers totaling 17,499. The study focused on readily available information on manufacturers such as ISO 9000 certification and publicly available emissions information reported to the EPA. Essentially this study looked at the correlation

of ISO 9000 certification, inventory levels of TRI listed hazardous materials, and TRI data. While this allowed for broad coverage and empirical data, these are insufficient measures of Leanness and Greenness.

Unlike the automotive study performed by Rothenberg, the King, Lenox study, finds a strong relationship between Lean manufacturing and toxic chemical reduction. They found that Lean facilities reduce emissions through pollution prevention rather than end-of-pipe solutions. This finding is consistent with Rothenberg. Also, King and Lenox found that firms are more likely to implement the ISO 14000 - International Environmental Management System Standard if they are already ISO 9000 certified. They also found that companies that implement Lean systems reduce emissions. "Studies cannot rule out the fact that Lean and Green may simply be by-products of a firm's innovative nature. (King, Lenox 2001)"

However, there is a problem with the King, Lenox study. Given that they were trying to perform a broad study based on generally available data, their definition of Lean manufacturing is questionable. Essentially, this study measures "Leanness" based on ISO9000 certification and the level of hazardous material inventories. The study finds that companies with low inventories of hazardous materials and who are ISO9001 certified, have lower toxic emissions than companies with higher inventories and that are not ISO9001 certified. It could be that the reason they have lower inventories of hazardous materials is because their manufacturing processes are more benign and, therefore generate less

toxic emissions. Also, the study finds that manufacturers that adopt ISO9000 are more likely to adopt ISO14000. It has been shown that ISO9000 certification provides an excellent foundation for ISO14000 implementation. Perhaps ISO9000 serves as a catalyst to ISO14000.

Proponents of the Lean and Green relationship observe that “zero waste” is the mantra of Lean manufacturing and suggest that pollution prevention will inevitably follow from this philosophy (Florida 1996, Hart, 1997). Lean manufacturing develops process improvement capabilities targeted toward reducing waste (Womack and Jones, 1990). Lean manufacturing requires workers to develop skills needed to reduce wastes, targeted by the Lean manufacturing doctrine (defects, over-production, transport, waiting, inventory, motion and excess processing) (MacDuffie, 1995). Once operators develop these skills, teaching them related skills that target environmental wastes may require less investment.

Thus, Lean manufacturing indirectly improves environmental performance by lowering the cost of waste reduction and by developing continuous improvement skills that are shared by both Lean and Green manufacturing programs. (King, Lenox 2001). Lean production may also reduce the cost of pollution prevention by lowering the cost of discovering pollution prevention opportunities. Lean production helps identify non-value added activities and the costs associated with them. Use of activity based cost systems are common among Lean practitioners. Such cost targeting techniques may provide managers with new

expectations of the potential costs and benefits of pollution reduction activities. Essentially, by developing tools to identify and reduce operational waste, Lean manufacturing 'greases the skids' for reducing environmental waste.

Theory suggests that a priori expectations and search costs can inhibit managers from uncovering existing opportunities for profit (Arrow 1974; Jensen 1982). If managers expect pollution-reduction to be costly, and it is difficult to do the measurement and analysis to test this expectation, managers may never investigate the real value of pollution reduction (Jensen 1982). As a result, opportunities for profitable pollution reduction may go unexploited. (King, Lenox 2001)

This study hypothesizes that Lean manufacturers are more likely to use source reduction rather than end-of-pipe treatment. The logic here is sound, in that Lean manufacturing focuses on eliminating waste at the source versus at the end of the process. Examples of this include the use of poke-yoke (mistake-proofing) and sequential inspection versus end of line inspection to reduce defects.

Rothenberg determined that Lean manufacturers relied almost exclusively on waste minimization versus end-of-pipe containment to reduce environmental waste emissions. (Rothenberg, 2001). The Lean philosophy views any non-value added process as wasteful and espouses stopping problems at the source.

The King, Lenox study suggests that Lean firms will have lower emissions than non-lean firms. This hypothesis is based on the fact that Lean companies already exploit waste reduction activities and this bleeds over to environmental waste reduction. Secondly, King and Lenox believe that Lean manufacturing serves as a catalyst to adopting environmental management systems, such as ISO14000. This is probably based on the fact that King and Lenox heavily weight the adoption of ISO9000 as a prime measure of Lean manufacturing.

Lean manufacturing has been found to directly improve environmental performance by reducing energy requirements for production (Rothenberg, 2001). However, Rothenberg found that Lean manufacturers actually have slightly elevated VOC/TRI emissions, because they do not use end-of-pipe containment systems. However, the overall waste generated is lower than companies that rely on end-of-pipe systems. End-of-pipe solutions simply change the medium of waste instead of eliminating it from occurring in the first place.

The sample for the King, Lenox study was based on manufacturers that reported their Toxic Release Inventory (TRI) to the EPA during the years of 1991 – 1996. By law, companies that manufacture more than 25,000 pounds or use more than 10,000 pounds of any of the listed chemicals, and employ at least 10 people throughout the year, must complete TRI reporting. The result was a sample of 17,499 facilities over a five year period, equaling 88,531 facility year observations.

The ISO14001 standard is the most prominent environmental management system in the United States. The standard was established in 1996, by the International Organization for Standardization. ISO14001 requires a facility to develop an environmental policy, set objectives, delineate organizational responsibilities, provide training and documentation, and monitor and correct deficiencies (ISO, 2002). It is the environmental analogue to the ISO9001 quality management standard. ISO14001 Adoption is coded simply as a dummy where

"I" indicates that a facility became ISO14001 certified sometime during the period 1996-1999. Certification data were gathered from the GlobeNet database of ISO14001- certified firms (GlobeNet, 2000).

This study used a variety of measures for environmental performance. They include; Toxic Release Inventory (TRI) Emissions, as reported to the EPA; Waste generation; On-site treatment; The adoption of the ISO14001 EMS standard. Since the data used for the study predates ISO14000 certifications in the use, ISO14000 certification is used as a dummy variable that post dates survey data. Given that the study focused exclusively on manufacturers that are large enough to require TRI reporting, they did a good job of assessing Greenness.

Unfortunately, the King, Lenox study implies that 'Leanness' can be measured by inventory levels of hazardous materials and ISO9000 certification. Inventory is in fact one of the seven wastes targeted by Lean manufacturing. Typically this applies to direct materials at various stages of production. Hazardous materials are often considered indirect materials, used for cleaning and processing. At least this is the case for discrete product manufacturing. So, this does not serve as a good measure of Leanness, when Lean systems focus mostly on the flow of products from the raw material stage to customer acceptance. Secondly, they chose to simply use ISO9000 certification to cover all other aspects of Lean manufacturing (i.e. work systems management). While ISO9000 leads to process standardization essential for Lean production, it is not a strong depiction

of Lean manufacturing. ISO9000 is a standard for quality systems, not Lean systems. Many companies that are ISO9000 certified are not Lean at all.

Finally, our findings further support the idea that potential complementarities exist among operational practices, and that firms should consequently consider adopting these practices in bundles (MacDuffie 1995; Milgrom and Roberts 1995). MacDuffie (1995) argues that when firms move to lean production, they should adopt a bundle of new inventory, technology, and work practices. Our research suggests that managers should consider including green practices in this bundle.' (King and Lenox, 2001)

The EPA Study

The EPA (2003) in collaboration with Ross & Associates, an environmental research and consulting firm in Seattle, WA conducted a study of Boeing Corporation to determine if Boeing's Lean manufacturing program generated environmental improvements. The study showed that Boeing's Lean manufacturing program reduced environmental waste as a byproduct of process efficiency and quality improvements associated with "Leaning" the manufacturing process. Secondly, they observed that the "waste reducing culture" associated with Boeing's Lean manufacturing program is exactly the type of culture the EPA has deemed essential for sustained environmental improvement. They also observed that Lean manufacturing programs/systems at Boeing and in general do not specifically address environmental waste reduction as a core objective of the program and considerable research opportunities exist to "build a bridge" between Lean and Green manufacturing systems. This study closely relates to the topic of this present study and for purposes of completeness excerpts from

the EPA/Ross & associates study of Boeing are included below. In particular, the study produced the following conclusions:

Lean produces an operational and cultural environment that is highly conducive to waste minimization and pollution prevention (P2). Lean methods focus on continually improving the resource productivity and production efficiency, which frequently translates into less material, less capital, less energy waste per unit of production. In addition, lean fosters a systematic, employee-involved, continual improvement culture that is similar to that encouraged by the public agencies' existing voluntary programs and initiatives, such as those focused on environmental management systems (EMS), waste minimization, pollution prevention, and Design for Environment, among others.

There is strong evidence that lean produces environmental performance improvements that would have had very limited financial or organizational attractiveness if the business case had rested primarily on conventional P2 return on investment factors associated with the projects. Conventional P2 return on investment factors include reductions in liability, compliance management costs, waste management cost, material input costs, as well as avoided pollution control costs. This research indicates that the lean drivers for culture change-substantial improvements in profitability and competitiveness by driving down the capital and time intensity of production and service processes-are consistently much stronger than the drivers that come through the "green door," such as savings from pollution prevention activities and reductions in compliance risk and liability.

This research found that lean implementation efforts create powerful coattails for environmental improvement. To the extent that improved environmental outcomes can ride the coattails of lean culture change, there is a win for business and a win for environmental improvement. Pollution prevention may "pay", but when associated with lean implementation efforts, the likelihood that pollution prevention will compete rises substantially.

Lean can be leveraged to produce environmental improvement, filling key "blind spots" that can arise during lean implementation. Although lean currently produces environmental benefits and establishes a systematic, continual improvement-based waste elimination culture, lean methods do not explicitly incorporate environmental performance considerations, leaving environmental improvement opportunities on the table. In many cases, lean methods have "blind spots" with respect to environmental risk and life-cycle impacts.

The research identified three gaps associated with these blind spots, that, if filled, could further enhance the environmental improvements resulting. First, lean methods do not explicitly identify pollution prevention and environmental risk as "wastes" to target for elimination. Second, in many organizations, environmental personnel are not well integrated into operations-based lean implementation efforts, often leading environmental management activities to operate in a "parallel universe" to lean implementation efforts. Third, the wealth of information and expertise related to waste minimization and pollution prevention that environmental

management agencies have assembled over the past two decades is not routinely making it into the hands of lean practitioners.

Despite these gaps, there is evidence that lean provides an excellent platform for incorporating environmental management tools such as life-cycle assessment, design for environment, and other tools used to reduce environmental risks and life-cycle environmental impacts.

Environmental Agencies have a window of opportunity to enhance the environmental benefits associated with lean. There is strong and growing network of companies implementing, and promoting, lean across the U.S. For those companies transitioning into a lean production environment, EPA has a key opportunity to influence their lean investments and implementation strategies by helping to explicitly establish with lean methods environmental performance considerations and opportunities. Similar, EPA can build on the educational base of lean support organizations – non-profits, publishers, and consulting firms – ensure they incorporate environmental considerations into their efforts.

EPA (2003)

Chapter Summary

This concludes the literature review section of this dissertation. Based on the detailed description of Lean and Green systems and previous studies regarding the relationship between them, it is clear that these two systems share a great deal in common and there is great potential for transcendence from Lean manufacturing to Green manufacturing. Following this section is chapter three that summarizes the literature review and identifies a research gap and describes how this dissertation study will fill that gap. Chapter three also describes the construction of a comparative model for Lean and Green manufacturing systems that forms the basis for the dissertation's quantitative analysis.

Chapter Three

Theoretical Constructs

Introduction

The literature review of chapter two summarizes previous research that describes Lean and Green manufacturing systems and the relationship between them. These studies showed evidence of shared best practices and environmentally beneficial byproducts resulting from Lean manufacturing implementation. However, these studies fell short of indicating whether Lean manufacturers transcend beyond the traditional boundaries of their Lean systems to embrace the broader Green manufacturing system that drives continuous environmental waste reduction. If so, then Lean manufacturing could be used as a catalyst to industrial sustainability: Industry in balance with Earth's capacity to generate natural resources and process industrial waste.

Summarizing the findings of the most recent Lean and Green manufacturing research yields the following conclusions.

First, both Lean and Green bodies of literature indicate that a systems approach is needed to create and sustain a culture for continuous waste reduction. The main high-level components common to both Lean and Green manufacturing systems can be categorized into three components. The *management system*

establishes formal management commitment to create the environment/culture conducive to waste reduction, the implementation of *waste reducing techniques* to physically transform products and processes to reduce waste, and measurable *results* to indicate to all stakeholders the benefits of the system.

Second, successful implementation of either Lean or Green manufacturing systems results in improvements that go beyond the traditional objectives of the respective system and have byproduct benefits that help to fulfill the objectives of the other system.

Third, Lean and Green systems share many best practices, that once implemented for one system can easily be utilized for the other system, assuming management chooses to commit the organization to implementation of the other manufacturing system.

Fourth, manufacturers are under competitive pressure to reduce operational waste (e.g. inefficiencies and quality defects) associated with Lean manufacturing. Manufacturers are also under growing public and regulatory pressure to reduce environmental waste, which if done properly lowers operating costs, improves public image, and reduces risks of liability. Thus, there is great motivation on the part of manufacturers to reduce waste associated with both systems, and to do this in the most efficient manner. This could lead to efforts to integrate Lean and Green systems.

Synthesizing these conclusions suggests that manufacturers, to use a legal analogy, have the motive, means and opportunity to transcend to Green manufacturing. The question is: Are they doing it? Specifically, to restate the research question: Are Lean manufacturers transcending to Green manufacturing? To answer this question adequately manufacturing plants must be assessed from a full manufacturing systems perspective. This requires instruments to measure a manufacturing plant's level of diffusion of Lean and Green manufacturing system components (a.k.a. best practices). The literature review explored the latest research on Lean and Green manufacturing systems to define the generally accepted components/best practices which comprise these two systems. These best practices provide the raw materials to develop a comparative research model. The purpose of this chapter is to build a comparative model for Lean and Green manufacturing systems, at a full system level. This model is utilized to conduct an empirical study to correlate the diffusion of Lean and Green manufacturing systems best practices.

Theory

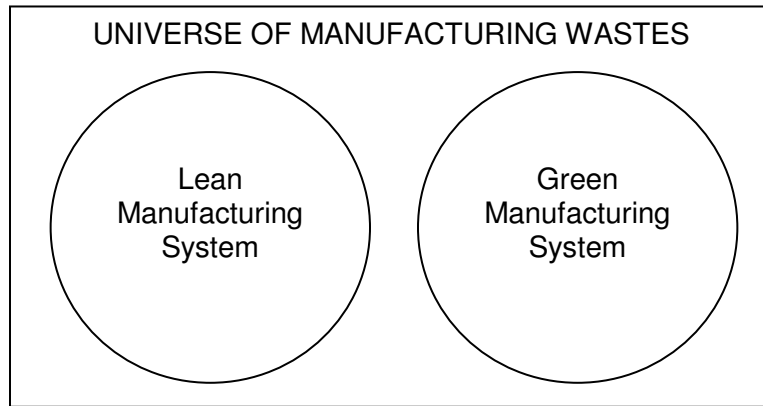
Synthesizing the body of Lean and Green literature painted an evolving relationship between these two systems that leads to a theoretical interpolation into the future. Philosophically speaking, Lean and Green manufacturing systems may start off targeting seemingly different types of waste, but eventually all manufacturing wastes affect the objectives of either system. Ultimately, the pursuit to become truly Green will require reducing operational wastes that

typically generate environmental waste as a result of process inefficiency.

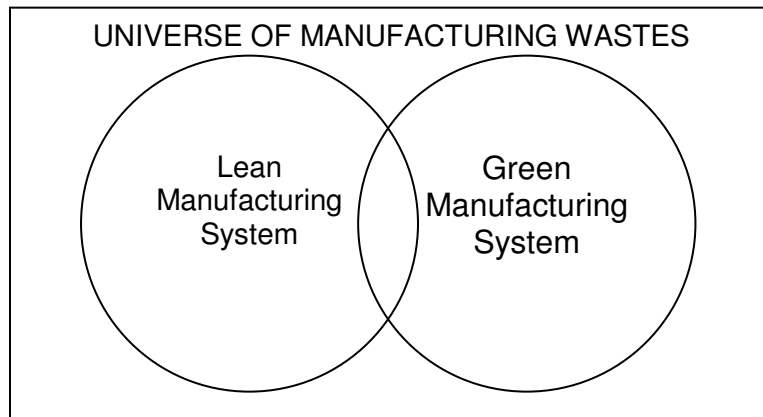
Likewise, to become truly Lean, one must address environmental wastes, which are almost always non-value added. So in the end, what begins as a pursuit to become Lean leads to becoming Green, and what begins as a pursuit to become Green leads to becoming Lean.

This abstract reasoning leads to several interesting research questions. If Lean companies are constantly looking for opportunities to reduce waste, and have developed skills and tools toward this end, do they naturally become Greener as they become Leaner? The exact same argument could be made if a company started down the Green path first. Do companies become Leaner as they become Greener? Would Green companies ultimately embrace Lean manufacturing best practices because a more efficient plant, which uses less energy and resources, is a more environmentally friendly plant? To borrow a phrase, is waste by any other name still waste?

It is helpful to describe this plausible evolution between Lean and Green systems into a series of Venn diagrams. These diagrams will serve to frame the discussion of what aspect of this evolution has been studied in previous research and what is yet to be studied. This will help shape the specific research model for this study, which contribute to moving the body of Lean and Green research to the next level.

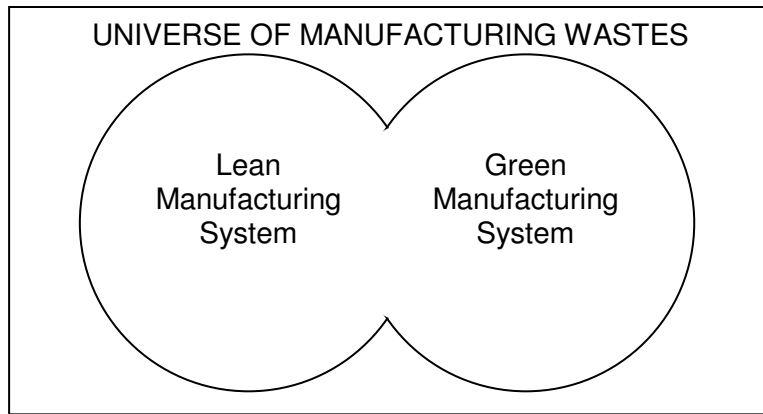


PARALLELISM: The traditional view whereby Lean and Green best practices are considered distinct sets of solutions targeting different forms of wastes. Some consider these efforts as conflicting. Best practices are administered by separate organizations operating in “parallel universes” of waste reduction.

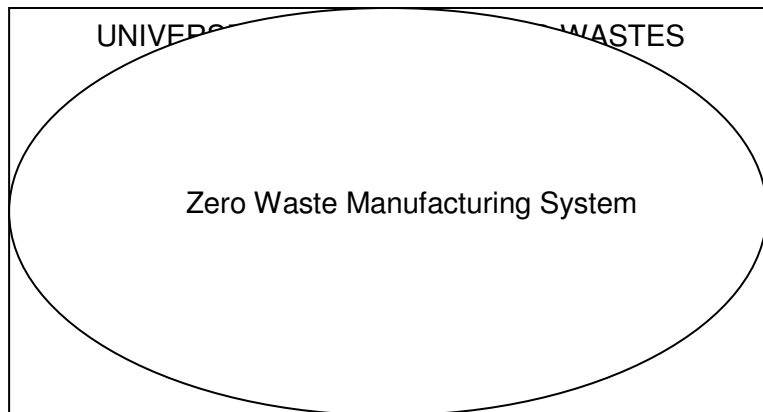


CONVERGENCE: The modern view, whereby Lean and Green best practices are considered complementary. Best practices from one discipline are successfully applied to reduce the other discipline’s wastes. Continuous improvement teams are starting to look at solutions that are both Lean and Green.

Figure 11. Evolution of Lean and Green Manufacturing Systems



TRANSCENDENCE: The view suggested in this study. Companies that are actively implementing Lean or Green manufacturing systems not only fully explore the common solutions (intersection of Lean and Green best practices) but also start down the path of implementing the other manufacturing system. Lean and Green manufacturing systems serve as a dual-catalyst to each other. Employees throughout the company implement a broad set of best practice targeting the full spectrum of wastes associated with both Lean and Green manufacturing systems.



SYNERGY: The Future, whereby distinctions between Lean and Green systems ends, and *Zero Waste Manufacturing* is the new holistic manufacturing system. Elimination of all forms of waste is the new corporate mantra. Synergy is realized as aggressive efforts to reduce waste results in continuous efficiency, quality, service and environmental improvements. New best practices evolve as new forms of waste are identified, beyond the present boundaries of Lean or Green wastes. The Earth itself serves as the model for manufacturing perfection and the

Figure 11. (Continued)

Research Model Construction

In order to determine if transcendence and/or synergy exists, comparative models of these two manufacturing systems that are consistent with scholarly research of the two systems are needed. This required the development of models for each system that were robust enough to capture the complexities of each system, yet simple enough to allow for meaningful correlation analysis between major factors of the two systems on an “apples to apples” basis.

Fundamentally, both Lean and Green manufacturing systems have three major factors: Management Systems, Waste Reducing Techniques, and Results. The management system defines the policies and procedures that create the environment/culture that commits the organization toward waste reduction, respective to each manufacturing system. Waste reducing techniques are the specific process (both business and production process) changes associated with each manufacturing system that result in waste reduction, respective to each manufacturing system. Results are the measurable improvements to the stated objectives of each manufacturing system. For example, the objective of Lean manufacturing systems is to lower operating costs, improve quality, and reduce cycle-time. The objective of Green manufacturing systems is to lower costs of environmental compliance and waste management, while reducing environmental impact.

Research on these two manufacturing systems typically looks for correlation between some combinations of these factors. A considerable amount of

research has been done to support the strong correlations between the factors within either Lean or Green manufacturing systems over the past fifteen to twenty years. Only recently (the past five to ten years) has meaningful research been done to explore the correlations between Lean and Green manufacturing systems. Already these studies are indicating statistically that there is correlation between the two manufacturing systems. Yet, there remains considerable research opportunity to complete the picture of full correlation between these two manufacturing systems, leading perhaps to a holistic waste reducing manufacturing system.

The following model diagram describes both Lean and Green manufacturing systems in their major components (management systems, waste reducing techniques, and results). Each block represents a set of criteria based on industry best practices. The arrows indicate the “independent to dependent” relationship supported by literature. The citations indicated in the model diagram support either the best practices associated with that part of the model and/or correlation analysis between sets of best practice criteria.

Clearly there is a research gap at the “Front end” of the model in terms of the correlation among the level of Leanness in general and the level of Green management systems. There is also only anecdotal evidence regarding correlation between waste reducing techniques between systems. That is to say that the Florida study (1996) indicated that Lean tools are being applied to the reduction of environmental waste, but not necessarily by Lean companies.

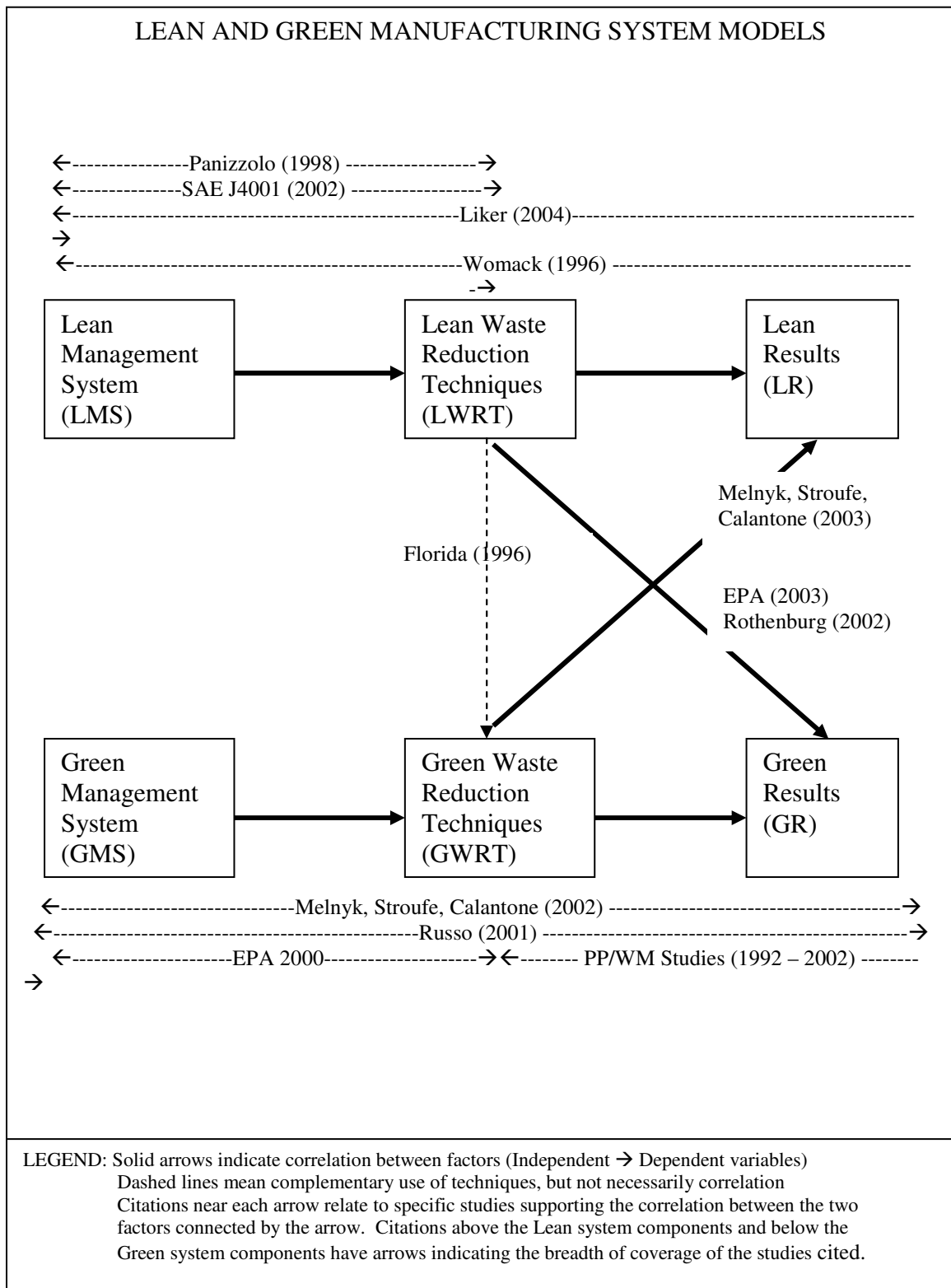


Figure 12. Lean and Green Manufacturing System Model

The diagram shows that previous studies have not addressed if the level of Lean system diffusion correlates to the level of diffusion of Green management system or Green waste reducing techniques. Rather, previous studies focus more on the results part of the model between Lean and Green systems. To determine if transcendence from Lean to Green manufacturing system diffusion exists, an empirical study can measure correlation between Lean and Green manufacturing systems components. To do this, valid measures of each system must be defined and instruments developed to measure the diffusion levels of Lean and Green manufacturing system components. An empirical approach of this nature requires cooperation from actual manufacturers, and was done through survey instruments, as opposed to on-site case studies, in order to stay within the resource constraints of the study.

With these considerations in mind, the leading models of Lean manufacturing in the literature were reviewed for their application in this dissertation study. The Toyota (4P) model described by Dr. Jeffery Liker (2004); the Society of Automotive Engineers (SAE) J4001 model (1999); and the Shingo Prize for Excellence in Manufacturing (2003) are all comprehensive models of the Lean manufacturing system. The J4001 and the Shingo models are already structured into assessment instruments, making them very practical for this type of research study. The Shingo criteria are unique in that a panel of five experts has been assessing Lean manufacturing plants according to the Shingo Prize model since 1988. In 2006 the Shingo Prize criteria became the basis for the new national Lean certificate program sponsored by the Society of Manufacturing Engineers

(SME) and the Association for Manufacturing Excellence (AME), working in collaboration with the Shingo Prize team. This is validation that the Shingo criteria are viewed as the gold standard for Lean, as confirmed by two leading manufacturing associations.

The instrument used by the Shingo Prize examiners is called the Shingo Prize scoring system. A team of five expert examiners collaborate to score a manufacturing plant's "Leanness", in eleven sub-categories that roll-up to three main categories (enablers, core operations, and results). These three categories are analogous to the three general categories described in the research model (i.e. management system, waste reducing techniques, and results). Shingo Prize scoring system data collected by the examiners is stored in a database and utilized to determine if a plant is a Shingo Prize recipient, finalist, or simply an applicant.

In the fall of 2004, Dr. Ross Robson (Executive Director of the Shingo Prize) indicated that he had recently become aware of the interest in Lean and Green manufacturing systems by being contacted by Ross and Associates, who were conducting a case study on the environmental benefits of Boeing's Lean program. This study is discussed in detail in the literature review. Dr. Robson was willing to support a study to survey the environmental practices of Shingo companies that had received site visits from examiners. This meant that an externally validated data set was available to serve as the measure for the Lean

manufacturing system. This meant that an equivalent measure for the Green manufacturing system was required to perform correlation analysis.

The selection criteria that were used to choose the Shingo criteria were applied to the selection of the Green manufacturing system instrument, with one twist. The Green manufacturing instrument would ultimately become a survey administered to the Shingo Prize manufacturing plants, which is a relatively small population ($n < 200$). This meant the survey had to be very user friendly, to assure a high response rate. Yet, it still had to adequately measure the broader Green manufacturing system. It also had to be general enough to be applied to the diverse set of discrete manufacturers that make up the Shingo plant population.

In reviewing the Green manufacturing literature, it was readily apparent that the survey instrument utilized by Melnyk et al (2003), struck a nice balance between breadth and brevity. It categorically covered the three main sections of the manufacturing system research model (management system, waste reducing techniques, and results). The Melnyk survey utilized the gold standard for environmental management systems (ISO14001), which is objectively measured through an independent annual audit of the manufacturing plant. The fourteen Green waste reducing techniques were all consistent with the EPA's guide for pollution prevention and waste minimization, considered the gold standard for industry. The ten results factors in the Melnyk survey were a robust balance of process and business metrics.

The survey instrument was already validated by the Melnyk team, and successfully applied to approximately eleven hundred discrete manufacturing plants. The statistics that came from the original Melnyk study could also serve as an interesting basis for comparison of the known Lean plants associated with the Shingo prize. The Melnyk study made a point of issuing their survey to a broad distribution of fifteen thousand discrete manufacturing plants listed in standard manufacturing databases.

Description of Research Model

The selection of Lean and Green manufacturing criteria was instrumental in shaping the hypotheses for this study. The committee agreed that “Gold Standard” Shingo criteria made for a strong independent measure of Lean. The Melnyk survey provides the complementary set of dependent variables for the study.

Survey data from the original Melnyk et al study of the general manufacturing population, and data from the Shingo plants were both utilized in the hypotheses. The Melnyk survey is also distributed to the Shingo plants so that comparison can be made to the general population and within the Shingo population utilizing the same set of Green variables. This assures an “apples to apples” comparison. This led to the research model and hypotheses stated below.

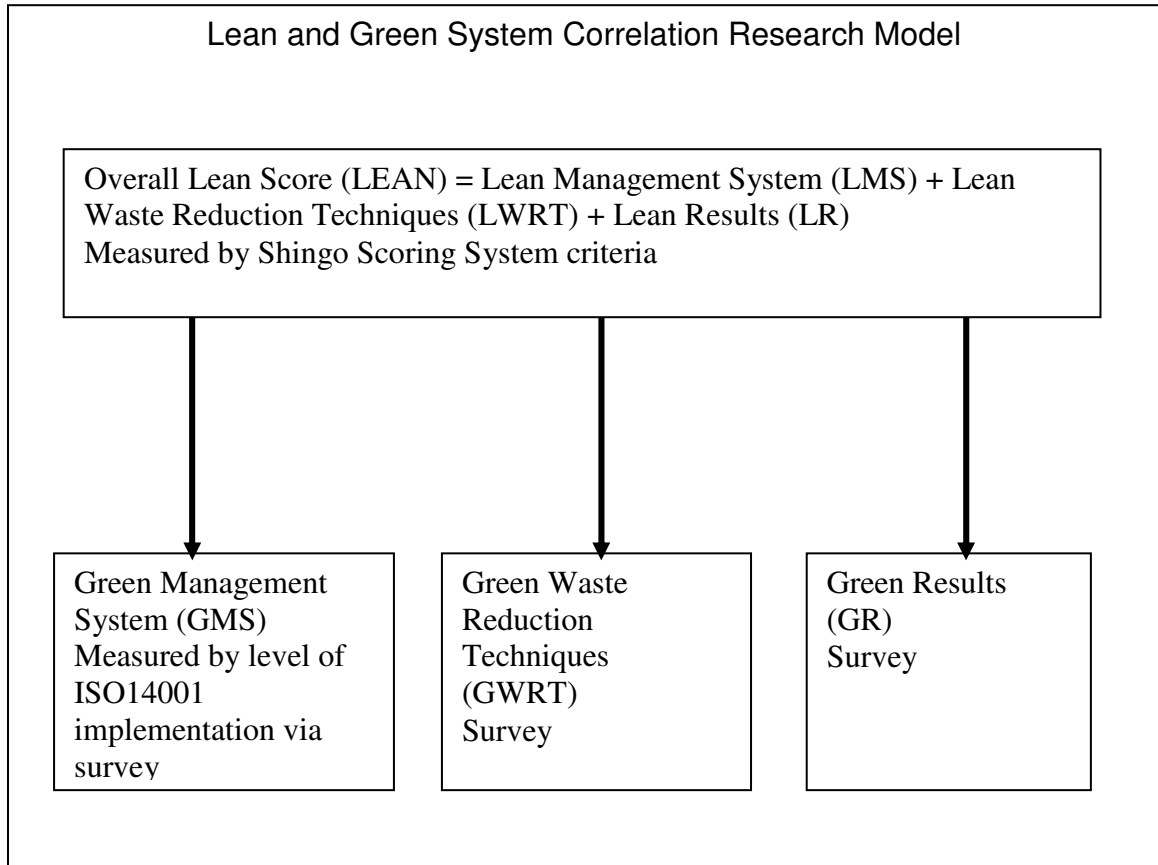


Figure 13. Research Model

The arrows in the diagram reflect the probable correlations between the variable “LEAN”, overall Shingo prize score, and the three variables Green management system (GMS), Green waste reducing techniques (GWRT), and Green results (GR). The model suggests that the level of Lean manufacturing system diffusion directly correlates to the levels of diffusion of the three environmental variables (GMS, GWRT, and GR).

Statement of Hypotheses

The research model led to the development of hypotheses to answer this research question empirically. The availability of the Shingo prize plants whose level of Leanness was measured by a panel of experts made for the ideal set of independent variables to determine if levels of diffusion of Lean manufacturing system components correlated to levels of diffusion of Green manufacturing system components. The set of three Green manufacturing system variables {Green management system (GMS), Green waste reducing techniques (GWRT), Green results (GR)} serve as the set of dependent variables for the stated hypotheses.

Hypothesis I is unique in that it compares the environmental performance of the set of Shingo plants with the set of general manufacturers surveyed originally in the Melnyk study a few years earlier. The intent of this hypothesis is to show that known Lean manufacturers are exhibiting significantly higher levels of environmental practices and results than the general manufacturing population. This would show evidence of Lean manufacturers *transcendence* to Green manufacturing.

Hypotheses II through IV are internally focused within the Shingo plants that responded to the survey. Respectively, these hypotheses relate to correlation between a plant's level of "Leanness" (LEAN) and its level of "Greenness" measured from the perspectives of the management system (GMS), waste reducing techniques (GWRT), and results (GR). The independent LEAN variable

is the total score from the Shingo Prize Scoring system. The Green dependent variables are taken from the three sections of the survey, each being the average score for that section. For ease of reference the hypotheses are listed below followed by a description of how the hypotheses were tested and the results of these tests.

Hypothesis I: Lean manufacturers, as recognized by the Shingo Prize team of examiners, are significantly Greener (as measured by GMS, GWRT, and GR variables) than the general population of manufacturers, identified in the original Melnyk study.

Hypothesis II: The overall Lean score (LEAN), as measured by the Shingo Prize examiners, positively correlates to the Green Management System score (GMS), as measured by the on-line Green survey.

Hypothesis III: The overall Lean score (LEAN), as measured by the Shingo Prize examiners, positively correlates to the Green Waste Reducing Techniques score (GWRT), as measured by the on-line Green survey.

Hypothesis IV: The overall Lean score (LEAN), as measured by the Shingo Prize examiners, positively correlates to the Green Results score (GR), as measured by the on-line Green survey.

Chapter Summary

This chapter synthesized leading research on Lean and Green manufacturing models, and previous research regarding their correlation. It then described a research gap to be filled and a practical means by which to fill the gap. The description of the research model and hypotheses for this dissertation study concludes chapter three. Chapter four will describe the specific research methodology used to test the hypotheses and perform full system correlation analysis.

Chapter Four

Methodology

Introduction

This chapter describes the methodology utilized to test the hypotheses described at the end of Chapter three and conduct full system correlation analysis. This entails the definition of variables associated with the research model, the development and testing of an on-line Green manufacturing system survey, survey administration, data collection, and statistical analysis utilized to test the hypotheses and perform full system correlation analysis.

Definition of Variables

While this study sought to understand all possible correlations between the components of both Lean and Green manufacturing systems, there was a decision to state hypotheses utilizing Lean variables as the independent variables and Green variables as the dependent variables. This was a logical choice, given that the Lean variables were known entities from the Shingo Prize database, validated by a panel of experts and the green variables were the unknown entity obtained by a survey administered to these Shingo companies. Control variables were also added to control external effects and minimize noise in the data.

Lean Independent Variables

The main lean independent variable LEAN is the total score from the Shingo prize scoring system database. It is the measure of an individual manufacturing plant that received a site visit from a team of five Shingo prize examiners. The team collaborated to create a single set of scores for the eleven sub-elements of the Shingo prize criteria. Each of the sub-elements has a range of potential points to earn, adding up to a total potential score of one thousand. Thus, LEAN is a continuous variable on a scale from zero to a thousand. The Shingo prize scoring system worksheet used by examiners indicates the point score for each of the eleven sub-elements and is shown in (table 7).

The sub-elements for the Shingo prize scoring system, comprise the Lean sub-variables of this study, and are grouped into three categories, associated with the research model (Lean management system (LMS), Lean waste reducing techniques (LWRT), and Lean results (LR)). The Lean independent variables are listed below, with their labels in parentheses. Detailed descriptions of each of the variables listed below can be found in the literature review, Chapter 2, and will also be referenced in detail in chapters five and six.

- Lean Management system (LMS) = IA + IB
 - Leadership (IA)
 - Empowerment (IB)
- Lean Waste Reducing Techniques (LWRT) = IIA+IIB+IIC+IID+III
 - Vision/Strategy (IIA)
 - Innovation (IIB)
 - Partnerships (IIC)

- Operations (IID)
- Support Functions (III)
- Lean Results (LR) = IVA+IVB+IVC+V
 - Quality (IVA)
 - Cost (IVB)
 - Delivery (IVC)
 - Customer Satisfaction & Profitability (V)
- Total Lean score (LEAN) = LMS + LWRT + LR

Table 7. Shingo Prize Scoring System Worksheet

Shingo Prize for Excellence in Manufacturing
Site Visit Evaluation Form

Company Name: _____
City, State: _____

Examiner Name: _____

149

	Points Possible	Percentage Awarded	Points Awarded	Subtotal
I. Leadership Culture & Infrastructure	150			0
A. Leadership	75		0	
B. Empowerment	75		0	
II. Manufacturing Strategy & Systems Integration	450			0
A. Manufacturing Vision & Strategy	50		0	
B. Innovations in Market Service & Product	50		0	
C. Partnering With Suppliers/Customers & Environmental Practices	100		0	
D. World Class Manufacturing Operations & Processes	250		0	
III. Non-Manufacturing Support Functions	100		0	0
IV. Quality, Cost & Delivery	225			0
A. Quality & Quality Improvement	75		0	
B. Cost & Productivity Improvement	75		0	
C. Delivery & Service Improvement	75		0	
V. Business Results	75		0	0
Customer Satisfaction and Profitability				
TOTAL POINTS	1000			0

Would you recommend this company receive a Shingo Prize?

- Strongly Recommend
- Recommend
- Not Recommend
- Strongly Not Recommend

Signature: _____

11/2/2006 _____

Green Dependent Variables

In chapter three, the argument was made to leverage the successful survey developed Melnyk et al in 2002. The Green dependent variables for this dissertation study will be taken directly from the Survey. Two variables that seemed redundant were not utilized from the original Melnyk survey. New labels, shown in parentheses for each variable were developed for this study to coincide with the three Green management system model components described in Chapter three (Green management system, Green waste reducing techniques, Green results).

- Green Management System (GMS)
 - Environmental management system/ISO14001 (GMS1)
 - Years ISO14001 certified (GMS2)
- Green Waste Reducing Techniques (GWRT)
 - Process redesign (GWRT1)
 - Product redesign (GWRT2)
 - Disassembly (GWRT3)
 - Substitution (GWRT4)
 - Reduce (GWRT5)
 - Recycling (GWRT6)
 - Remanufacturing (GWRT7)
 - Consume internally (GWRT8)
 - Prolong use (GWRT9)
 - Returnable packaging (GWRT10)
 - Spreading risks (GWRT11)
 - Creating markets (GWRT12)
 - Waste segregation (GWRT13)
 - Alliances (GWRT14)

- Green Results (GR)
 - Reduced costs (GR1)
 - Reduced lead-times (GR2)
 - Improved product quality (GR3)
 - Improved market position (GR4)
 - Enhanced reputation (GR5)
 - Improved product design (GR6)
 - Reduced process waste (GR7)
 - Improved equipment selection (GR8)
 - Benefits outweigh costs (GR9)
 - Improved international sales (GR10)
- Total Green Score (GREEN) = normalized sum {GMS, GWRT, GR}

Control Variables

Control variables were included to understand external influences on the variables under study. Based on discussions with the Shingo team and committee members, three control variables were chosen; *quartile* of lean scores, *country* of plant location, and *year* of Shingo site visit and assessment. This data resided in the Shingo prize scoring system database and made available by the Shingo team.

Quartile was chosen as a control variable, because it was thought that blocking the Shingo respondents into groups may provide a more discrete view of whether higher levels of greenness were associated with the highest scoring Lean plants versus the lowest scoring lean plants. A simple point value was assigned to the four quartiles of respondents based on the total Lean score from the Shingo prize scoring system database. The definition of each quartile is below with the actual point value assigned in parentheses.

- Quartile 1: Lowest fourth of LEAN scores (1)
- Quartile 2: Second lowest fourth of LEAN scores (2)
- Quartile 3: Second highest fourth of LEAN scores (3)
- Quartile 4: Highest fourth of Lean scores (4)

Country was chosen as a control variable because the three North American countries that are part of the Shingo database each have unique environmental regulations. It is believed that this could influence the environmental behaviors of the plants in the study. The definition for each country is below with the actual point value assigned in parentheses.

- United states: Plant located in the United States of America (1)
- Mexico: Plant located in the country of Mexico (2)
- Canada: Plant located in the country of Canada (3)

Year was chosen as a control variable because changes in both Lean and Green behavior could have occurred since the year the plant received its Shingo site visit. Additionally, the data set was limited to five-years back so that the lag between Lean and Green assessment would not be too great. The value assigned to the variable year is the actual year the sight assessment was performed ranging from 2000 to 2005.

Survey Instrument

Consistent with the three main manufacturing system components the survey has three sections (Management system, waste reducing techniques, and results). Survey section one, Green management system, has two questions that address the status and maturity of the plants environmental management

system implementation. Survey section two, Green waste reducing techniques, is comprised of fourteen questions regarding specific practices the plant undertakes to reduce environmental waste. Survey section three, results, is comprised of ten questions that address the process and business results of Green manufacturing efforts in the plant. The survey questions align directly with the aforementioned Green dependent variables.

Regarding survey scales, for section one, Green management system, the original seven-point scale from Melnyk was utilized. This was because the scale labels were descriptive specific to the status of the Green management system. For survey section two, waste reducing techniques, and section three, results, the original Melnyk survey scale was a simple numeric scale ranging from zero to ten. Committee members thought it would be more “user friendly” if I chose a common Likert scale with descriptive labels, rather than a numeric scale. Concern that changing the scale may change the reliability of the survey instrument, led to research on survey scales.

The research confirmed that as long as the scale is between five and eleven choices, there was no discernable difference in the reliability of the scale. This research also confirmed what committee members stated that the scale should be easily understood and not be confusing, as this could lead to frustration and adversely affect response. The decision was made to select five-point Likert scales for section two (waste reducing techniques) and section three (results) survey question. The labels for the scale were based on recommendations from

the literature that had proven user friendly in the past. A Not applicable (N/A) option was added for each question, so as not to force the respondent to answer a question erroneously if it truly did not apply to their plant. Survey scale research also confirmed that the addition of an N/A option was helpful in reducing the frustration of survey respondents.

A linear transformation was prescribed by Dr. Brannick to normalize the original Melnyk eleven-point scale and this studies five-point scale, for survey sections two and three. This allowed for a fair comparison of means to test hypothesis one. The statistical methods used to test hypothesis I are described in detail in chapter five.

On-line Survey Development

I was fortunate to collaborate with the Shingo Prize team to conduct this study. Their advice on survey design and administrative techniques, and the access they provided to their Shingo database, greatly shaped the survey design and overall methodology of this study. It was the advice of the executive director Dr. Ross Robson, Executive director of the Shingo Prize, that the survey be put on-line to ease distribution and enhance response rate. He had previous success sending out invitation surveys, with the link to the on-line survey within the body of the email, and requested that I take a similar approach. The committee agreed with this approach, and I was provided resource of Chris Paulus at USF to create an on-line version of the Melnyk survey. A copy of the on-line survey can be seen in (table 8)

An online data table was created to capture survey responses. A privacy code was established for each plant to anonymously key their survey responses to their Shingo Prize scoring system data. Point values for the Likert scales ranged from one to seven in section one and from one to five for sections two and three. For clarity, scales for each section of the survey are listed below with their point values in parentheses. The N/A response was recorded as a zero response to indicate that the respondent in fact chose this response, but was later changed to a non-value, so as not to skew the results.

- Scale for survey section 1: Green Management System

(1) Not being considered	(5) Currently implementing
(2) Future consideration	(6) Successfully implemented
(3) Assessing Suitability	(7) ISO14001 certified
(4) Planning to implement	() Not applicable

- Scale for survey section 2: Green Waste Reducing Techniques

Almost never	Rarely	Sometimes	Often	Almost always	N/A
(1)	(2)	(3)	(4)	(5)	()

- Scale for survey section 3: Green Results

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	N/A
(1)	(2)	(3)	(4)	(5)	()

Table 8. On-line Survey Instrument



My name is Gary Bergmiller and I am an Industrial Engineering Ph.D. student at the University of South Florida, conducting research to fulfill my dissertation requirements. This research is supported by Dr. Ross Robson The Executive Director of the Shingo Prize, of Utah State University . The survey is only twenty-five questions long and should take less then five minutes to complete. By completing this brief survey you will be advancing important research on the relationship between Lean manufacturing best practices and Green (environmental) manufacturing best practices. Confidentiality of the data will be assured by the use of a privacy code, instead of company name, to which only Dr. Ross Robson's staff has access. If you have any questions please contact me at 727 709-5969 or gbergmiller@yahoo.com. Thank you for taking the time to complete this important survey.

Please enter your privacy code here:

Please Read Instructions Carefully

- 1) For each question, please select the cell which best describes its status in your company (only one selection per row please)
- 2) Please collaborate with appropriate professionals in your organization as needed to assure accuracy in answering the following questions
- 3) Please answer all questions, if question does not apply to your plant select "Not applicable"
- 4) Please press the "Submit Form" button when you have answered the last survey question

1. Status of your plant's Environmental Management System (ISO 14001):

- | | |
|--|---|
| <input type="checkbox"/> Not Being Considered | <input type="checkbox"/> Currently Implementing |
| <input type="checkbox"/> Future Consideration | <input type="checkbox"/> Successfully Implemented |
| <input type="checkbox"/> Assessing Suitability | <input type="checkbox"/> ISO14001 Certified |
| <input type="checkbox"/> Planning to implement | <input type="checkbox"/> Not Applicable |

If your plant's environmental management system is ISO14001 certified, how many years has that system been in place? years.

2. To what extent are the following environmental waste reducing techniques considered within your plant?	Almost Never	Rarely	Sometimes	Often	Almost Always	Not Applicable
Product redesign: redesigning the product to eliminate any potential environmental problems (manufacturing or recycling)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Process redesign: redesigning the process to eliminate any potential environmental problems	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Disassembly: redesigning the product or process so as to simplify disassembly and disposal at the end of the product's useful life	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Substitution: replacing a material which can cause environmental problems with another material which is not problematic	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Reduce: reducing the level of material and/or components (which are contributing to environmental problems) within products	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Recycling: making more use of recycled components or making a product which is more easily/readily recycled	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Remanufacturing: restoring used durable products to "new" condition, to be used in their original function, by replacing worn or damaged parts	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Consume internally: consuming waste internally (e.g. wood pallets used in shipping or product storage used to generate electrical power in co-generation facility)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Prolong Use: reducing environmental problems by increasing the overall life of the product (e.g. engines which last longer before having to be replaced or rebuilt)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Returnable packaging: Using packaging and pallets which can be returned after they are finished being used	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Spreading Risks: shifting responsibilities for environmental problems to a third party or expert better able to deal with issues	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Creating a market for waste products: treating waste as an input to another product which can be made and sold at a profit	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Waste Segregation: an intermediate action in which waste streams are separated out into their individual components before being recycled, reused or consumed internally	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Alliances: working with either suppliers or consumers to address environmental problems and/or issues	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Table 8. (Continued)

3. Results: Environmental activities within your plant have :	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Not Applicable
Significantly reduced overall costs	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Significantly reduced lead-times	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Significantly improved product quality	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Significantly improved its position in the marketplace	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Helped enhance the reputation of your company	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Helped your company design/develop better products	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Significantly reduced waste within the production process	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Significantly reduced waste within the equipment selection process	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Had benefits that have definitely outweighed any costs incurred	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Improved its chances of successfully selling its products in international markets	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Thank you very much.

Submit Form	Reset Form
-----------------------------	----------------------------

Survey Testing

Upon completion of the on-line version of the survey, Chris Paulus and I tested the survey to assure the correct point values, for the Likert scales were entered into the database. As a final test of content validity, the survey was sent to several Green manufacturing professionals and several Shingo prize examiners. The group of five experts confirmed that the survey struck a nice balance between brevity and depth, and was a survey instrument that would accurately assess Green manufacturing practices.

Additionally, I solicited the help of ten associates to take the survey and offer a critique. The survey testers were asked to judge the survey on clarity, ease of use, and overall time required to take the survey. The consensus view was that the survey was understandable and easy to use. Time to take the survey averaged around five minutes.

Once tested, I submitted my research proposal and survey to the Institutional Review Board (IRB). Shortly thereafter, I received a list of eight issues requiring resolution, prior to their approval. After several weeks of collaboration with those referenced in the issues letter, I was able to receive formal approval to commence with the study (figure 14).

November 9, 2006

RE: **Exempt Certification** for Application for Exemption
IRB#: 103870

Title: *Lean Manufacturers Transcendence To Green Manufacturing: Correlating the
Diffusion of Lean and Green Manufacturing Systems*

Dear Dr. Bergmiller and Dr. Yalcin:

On August 31, 2005, the Institutional Review Board (IRB) determined that your Application for Exemption **MEETS FEDERAL EXEMPTION CRITERIA number two (2) and number four (4)**. It is your responsibility to ensure that this research is conducted in a manner consistent with the ethical principles outlined in the Belmont Report and in compliance with USF IRB policies and procedures.

Please note that changes to this protocol may disqualify it from exempt status. It is your responsibility to notify the IRB prior to implementing any changes.

The Division of Research Compliance will hold your exemption application for a period of five years from the date of this letter or until a Final Review Report is received. If you wish to continue this protocol beyond the five-year exempt certification period, you will need to submit an Exemption Certification Request form at least 30 days before this exempt certification expires. The IRB will send you a reminder notice prior to expiration of the certification; therefore, it is important that you keep your contact information current. Should you complete this study prior to the end of the five-year period, you must submit an Application for Final Review.

Please reference the above IRB protocol number in all correspondence to the IRB or the Division of Research Compliance. In addition, we have enclosed an Institutional Review Board (IRB) Quick Reference Guide providing guidelines and resources to assist you in meeting your responsibilities when conducting human subjects research. Please read this guide carefully.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to the Human Research Protections Program.

If you have any questions regarding this matter, please call 813-974-9343.

Sincerely,



Paul G. Stiles, J.D., Ph.D.
USF Institutional Review Board

IA-EC-05-01

Figure 14. IRB approval

Survey Administration and Data Collection

Starting in November of 2005, email survey invitations were sent to the representative at the plant who was the established contact in the Shingo prize database. Recipients were encouraged to collaborate with environmental professionals at their facilities for accuracy. A unique privacy code was included in the body of the email and a link to the on-line survey. The survey initially was sent from the email address of the graduate student (Preston) at Utah State University (USU) tasked with adding privacy codes and send invitations. I was unable to send the emails, to assure anonymity of the privacy codes.

The initial response to the emails was very poor, two or three responses. Upon discussion with the Shingo team and close examination of the email, it became evident that there were formatting problems and the recipients were probably unfamiliar with the email address associated with the invitation. Formatting issues were addressed, and Dr. Ross Robson (executive director) agreed to have the invitation letters sent from his email address. This greatly improved response rate in the month of December 2005.

In January I was allowed to perform follow-up phone calls. I was provided contact information, but not privacy codes. Upon reaching someone, I would ask them if they had received and retained the email invitation. If not, I contacted Preston at USU to have him resend the email to this person, with their unique privacy code. Roughly fifty percent of the contact information was invalid, as over the years these highly mobile professionals had moved on.

In some cases I was forwarded to the environmental professional at the plant and some were willing to take the survey. Unfortunately, the advent of automated operators that require phone extensions, made this challenging in many cases. The follow-up phone call process was very time consuming, but yielded eleven more responses to the survey, making the effort well worth it. Once all reasonable email and phone call invitation options were exhausted, upon the committee members' advice, Survey administration efforts terminated in February of 2006. The focus of the study no shifted to analyzing the data.

Sample Size and Statistical Analysis

The unit of analysis for this study is the individual manufacturing plant. The reason for this decision is that two of the major externally validated measures (Shingo prize site visit scores and ISO14001 certification), are administered at the plant level. The Shingo team limited access to plants that had received site visits during the years from 2000 to 2005, to assure accuracy of the data. A total of one hundred-twenty plants were invited to take the survey of which fifty-one plants responded, and forty-seven responses were usable. This made for a survey response rate of thirty-nine percent.

For the plants that participated in the study, the Shingo team graciously provided full and confidential access to the Shingo Prize scoring system database. The data set from the survey was merged with the data from the Shingo prize scoring system, keyed by the privacy code. Prior to this point, I believed I would only have knowledge of the plants overall status (i.e. applicant, finalist, or prize

recipient), and stated my hypotheses accordingly. Access to the scoring system data allows for more complete correlation analysis at the sub-factor level and a much stronger dissertation study.

Based on recommendations of my research committee, I purchased SAS statistical software to analyze the data. Reliability of the data sets was confirmed using Cronbach's coefficient Alpha tests and repeating findings from previous Lean and Green studies. Hotelling's T-tests was utilized to test hypothesis I, comparing the means of the overall Shingo respondents to the means of the general manufacturing population, studied previously by Melnyk et al. Pearson's product moment correlation coefficients were utilized to determine significant correlations between all variables in the study. Regression analysis was utilized to determine multi-variant effects on study variables. The complete statistical analysis is detailed in Chapter five: Data Analysis and Results.

Chapter Summary

This chapter explained the methods used to test the hypotheses associated with the research model defined in Chapter three. Chapter four explained the steps to create and administer a Green manufacturing survey, whose data served as the set of dependent variables for the study. The survey was directed at known Lean manufacturing plants that had received site visits from Shingo prize examiners. The Shingo prize scoring system data served as the set of independent variables for the study. Control variables were also introduced to minimize noise and account for external effects not controlled by this study. Data collection steps

were explained in detail and statistical methods utilized to analyze the data were summarized and will be described in detail in chapter five.

Chapter Five

Data Analysis and Results

Introduction

Lean manufacturing data from the Shingo prize scoring system database and Green manufacturing data collected from the on-line survey were analyzed to validate the data sets, test the four main hypotheses, and identify statistical relationships between sub-variables. Two statistical approaches were employed to validate both the Lean data set and the Green data set. The Cronbach coefficient alpha test was applied to all variables to assure the reliability of the measurement instrument for each variable. Secondly, correlation analysis was performed within the sets of Lean and Green variables to confirm the results of earlier studies. Specifically, the analysis was intended to show that within both Lean and Green data sets, Management System scores correlate significantly to Waste Reducing Technique scores, which in turn correlate significantly to Results scores.

Hypothesis one utilized T-Tests to compare the statistics of known Lean “Shingo” plants to the statistics of the general manufacturing population, derived in the study where the Green manufacturing survey originated (Melnik et. al., 2002). Hypotheses two through four were tested using Pearson’s product moment correlation coefficient to determine significant correlations between the main

Lean and Green variables within the Shingo plant population. Full correlations analysis was performed between all sub-variables in the study to identify any possible correlations. Multi-variant regression analysis was performed on all logical combinations of variables in the research model, to identify any possible multi-variant effects. All of this is described in detail below.

Presentation of Data

The data set has two major subsets, one set obtained from the Shingo Prize scoring system database and one set obtained from the on-line survey. The independent and control variables are from the Shingo database, and the dependent variables are obtained from the Green on-line survey administered to the Shingo plants. The data sets were merged using the unique privacy code provided in the Shingo team survey invitations to all eligible plants (received site visits between 2000 – 2005). There were a hundred and ten plants that received the survey invitation, of which fifty-one plants responded, and forty-seven responses were usable. The simple statistics for the complete data set are shown below in table 9.

Table 9. Simple Statistics for Data Set

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
Quartile	47	2.53191	1.12000	119.000	1.00000	4.00000
Country	47	1.21277	0.41369	57.000	1.00000	2.00000
Year	47	2004	1.27960	94169	2001	2005
IA	47	59.68085	6.30082	2805	45.00000	69.00000
IB	47	54.14894	8.83171	2545	32.00000	67.00000
LMS	47	113.82979	14.06247	5350	79.00000	136.00000
IIA	47	38.70213	4.48143	1819	25.00000	45.00000

Table 9. (Continued)

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
IIB	47	38.48936	5.04705	1809	22.0000	53.00000
IIC	47	65.76596	12.08163	3091	34.0000	90.00000
IID	47	181.34043	21.86746	8523	123.00000	220.00000
III	47	79.97872	13.73901	3759	50.00000	106.00000
LWRT	47	404.27660	36.27534	19001	288.00000	471.00000
IVA	47	57.51064	6.49372	2703	44.00000	71.00000
IVB	47	57.29787	6.46702	2693	30.00000	71.00000
IVC	47	60.17021	7.47843	2828	41.00000	71.00000
V	47	59.85106	6.77906	2813	45.00000	70.00000
LR	47	234.82979	18.14353	11037	185.00000	274.00000
LEAN	47	752.93617	56.11456	35388	568.00000	851.00000
GMS1	47	5.82979	2.24886	274.00000	1.00000	7.00000
GMS2	47	3.57447	2.84181	168.00000	0	10.00000
GMS	47	9.40426	4.62347	442.00000	1.00000	17.00000
GWRT1	42	3.61905	1.01097	152.00000	1.00000	5.00000
GWRT2	46	4.17391	0.76896	192.00000	2.00000	5.00000
GWRT3	42	3.02381	1.23936	127.00000	1.00000	5.00000
GWRT4	47	4.12766	0.92353	194.00000	1.00000	5.00000
GWRT5	46	3.97826	0.82970	183.00000	1.00000	5.00000
GWRT6	46	3.82609	1.17954	176.00000	1.00000	5.00000
GWRT7	41	2.90244	1.26105	119.00000	1.00000	5.00000
GWRT8	42	3.00000	1.22971	126.00000	1.00000	5.00000
GWRT9	44	3.54545	1.17046	156.00000	1.00000	5.00000
GWRT10	47	4.19149	0.96995	197.00000	1.00000	5.00000
GWRT11	42	3.26190	1.06059	137.00000	1.00000	5.00000
GWRT12	40	3.17500	1.41217	127.00000	1.00000	5.00000
GWRT13	45	4.37778	0.80591	197.00000	1.00000	5.00000
GWRT14	47	3.72340	1.05711	175.00000	1.00000	5.00000
GWRT	47	3.66474	0.62402	172.24274	1.78571	4.64286
GR1	47	3.91489	0.85541	184.00000	2.00000	5.00000
GR2	42	3.09524	0.82075	130.00000	2.00000	5.00000
GR3	46	3.43478	0.98098	158.00000	2.00000	5.00000
GR4	47	3.63830	0.81895	171.00000	2.00000	5.00000
GR5	47	4.29787	0.62258	202.00000	3.00000	5.00000
GR6	45	3.62222	0.88649	163.00000	2.00000	5.00000
GR7	47	4.19149	0.79778	197.00000	2.00000	5.00000
GR8	47	3.74468	0.79312	176.00000	2.00000	5.00000
GR9	46	3.93478	0.67994	181.00000	2.00000	5.00000
GR10	47	3.87234	0.82402	182.00000	2.00000	5.00000
GR	47	3.78457	0.54886	177.87500	2.80000	4.80000
GREEN	47	0.68102	0.12841	32.00785	0.35199	0.89238

Validation of Data

Two statistical approaches were employed to validate both the Lean data set (independent variables) and the Green data set (dependent variables). The Cronbach coefficient alpha test was applied to all variables to assure reliability of the measurement instrument for each variable. Secondly, correlation analysis was performed within the data sets of dependent and independent variables to confirm the results of earlier studies (i.e. Management System scores correlate significantly to Waste Reducing Technique scores, which in turn correlate significantly to Results scores). The Cronbach coefficient alpha test was performed for all 48 variables in the study to assure reliability of each variable as a measurement instrument. The following is a brief description of the Cronbach coefficient alpha test:

Cronbach's coefficient alpha estimates the reliability of the scale by determining the internal consistency of the test or the average correlation of items within the test (Cronbach 1951). Repeated measurements for a series of individuals will show some consistency. Reliability measures internal consistency from one set of measurements to another. The observed value Y is divided into two components, a true value T and a measurement error E . The measurement error is assumed to be independent of the true value, that is,

$$Y = T + E \quad \text{Cov}(T, E) = 0$$

The reliability coefficient of a measurement test is defined as the squared correlation between the observed value Y and the true value T , that is,

$$r^2(Y, T) = [(Cov(Y, T))^2 / V(Y) V(T)] = [(V(T))^2 / V(Y) V(T)] = [V(T) / V(Y)]$$

which is the proportion of the observed variance due to true differences among individuals in the sample. If Y is the sum of several observed variables measuring the same feature, you can estimate $V(T)$. Cronbach's coefficient alpha, based on a lower bound for $V(T)$, is an estimate of the reliability coefficient.

When the correlation between each pair of variables is 1, the coefficient alpha has a maximum value of 1. With negative correlations between some variables, the coefficient alpha can have a value less than zero. The larger the overall alpha coefficient, the more likely that items contribute to a reliable scale. Nunnally and Bernstein (1994) suggests 0.70 as an acceptable reliability coefficient; smaller reliability coefficients are seen as inadequate.

Listwise deletion of observations with missing values is necessary to correctly calculate Cronbach's coefficient alpha. PROC CORR does not automatically use listwise deletion if you specify the ALPHA option. Therefore, you should use the NOMISS option if the data set contains missing values.
(SAS, 2006)

As suggested the NOMISS ALPHA function was utilized to avoid missing values and assure the statistical power of the Cronbach test. All variables utilized in the study exceeded the 0.70 reliability coefficient threshold (Nunnally, Bernstien, 1994), indicating acceptable reliability of the entire data set. Table 10 shows Cronbach coefficient alphas for all forty-eight variables utilized in this study.

Table 10. Cronbach Coefficient Alphas for Variables

Cronbach Coefficient Alpha				
		Variables	Alpha	
		Raw	0.792510	
		Standardized	0.889711	

Cronbach Coefficient Alpha with Deleted Variable				
Deleted Variable	Raw Variables		Standardized Variables	
	Correlation with Total	Alpha	Correlation with Total	Alpha
Quartile	0.843355	0.790260	0.465505	0.886116
Country	-.024788	0.792897	0.390706	0.887164
Year	-.002980	0.792935	-.238800	0.895672
IA	0.678571	0.782981	0.051250	0.891821
IB	0.587173	0.781509	0.236300	0.889302

Table 10. (Continued)

Deleted Variable	Correlation with Total	Alpha	Correlation with Total	Alpha
LMS	0.687847	0.773178	0.183555	0.890025
IIA	0.546041	0.786183	-.078742	0.893561
IIB	0.496145	0.785355	-.033785	0.892962
IIC	0.158174	0.791676	-.191657	0.895054
IID	0.739818	0.760231	0.222568	0.889491
III	0.440988	0.781589	0.361629	0.887569
LWRT	0.832434	0.747897	0.215885	0.889583
IVA	0.444998	0.784998	0.307940	0.888314
IVB	0.432834	0.785406	0.589458	0.884361
IVC	0.268346	0.788747	0.164639	0.890283
V	0.360804	0.786802	0.205377	0.889727
LR	0.538862	0.774057	0.500710	0.885620
LEAN	0.983572	0.762830	0.387892	0.887203
GMS1	0.333967	0.790719	0.549172	0.884934
GMS2	-.040153	0.793476	0.293940	0.888508
GMS	0.128559	0.791808	0.452676	0.886296
GWRT1	-.153083	0.793297	0.215652	0.889586
GWRT2	-.157822	0.793212	0.166796	0.890254
GWRT3	-.075067	0.793177	0.582088	0.884466
GWRT4	0.101925	0.792617	0.531179	0.885189
GWRT5	0.117954	0.792638	0.444371	0.886413
GWRT6	0.117166	0.792522	0.366231	0.887505
GWRT7	-.029964	0.793030	0.347065	0.887772
GWRT8	0.084889	0.792642	0.476089	0.885967
GWRT9	0.106873	0.792572	0.504106	0.885572
GWRT10	0.136777	0.792546	0.468129	0.886079
GWRT11	0.020822	0.792841	0.215022	0.889594
GWRT12	0.166331	0.792256	0.492246	0.885739
GWRT13	0.183284	0.792428	0.398746	0.887052
GWRT14	-.137190	0.793318	0.502528	0.885594
GWRT	0.071505	0.792757	0.760716	0.881900
GR1	-.051243	0.793024	0.489833	0.885773
GR2	-.177066	0.793357	0.420145	0.886752
GR3	-.466179	0.794177	0.200611	0.889792
GR4	0.126283	0.792589	0.613550	0.884017
GR5	-.151506	0.793142	0.451020	0.886319
GR6	-.044812	0.793015	0.443063	0.886431
GR7	0.102847	0.792670	0.498411	0.885652
GR8	0.106427	0.792651	0.538520	0.885085
GR9	0.096134	0.792685	0.468108	0.886079
GR10	-.123914	0.793180	0.262671	0.888940
GR	-.091637	0.793033	0.632830	0.883742
GREEN	0.108041	0.792828	0.744730	0.882131

The other method used to validate the data set was to verify significant correlations within Lean and Green manufacturing system main variables, identified by previous research efforts found in the literature review. Both Lean and Green literature indicate that the Management System correlates strongly to the Waste Reducing Techniques, which in-turn correlate strongly to Results [(Melnyk, et. al. 2003)(Russo, 2001)(SAE, 1999)(Shingo, 2006)]. While there is no attempt at proving causality in this study, I was able to show significant correlation between the main variables as stated above.

The SAS PROC CORR (process correlation) function was utilized to determine correlation between independent and dependent variables. SAS primarily utilizes the Pearson product-moment correlation to compute “Pearson correlation coefficient” between the main Lean variables and between the main Green variables in question. As required SAS may apply additional correlation methods in addition to the Pearson product-moment correlation function when the PROC CORR function is invoked. The SAS correlation methods associated with the PROC CORR function are summarized below:

The Pearson product-moment correlation is a parametric measure of association for two variables. It measures both the strength and direction of a linear relationship. If one variable X is an exact linear function of another variable Y, a positive relationship exists if the correlation is 1 and a negative relationship exists if the correlation is -1. If there is no linear predictability between the two variables, the correlation is 0. If the two variables are normal with a correlation 0, the two variables are independent. However, correlation does not imply causality because, in some cases, an underlying causal relationship may not exist. Probability values for the Pearson correlation are computed by treating

$$t = (n-2)^{1/2} \left(\frac{r^2}{1-r^2} \right)^{1/2}$$

as coming from a *t* distribution with (*n*-2) degrees of freedom, where *r* is the sample correlation.

Spearman rank-order correlation is a nonparametric measure of association based on the ranks of the data values. PROC CORR computes the Spearman correlation by ranking the data and using the ranks in the Pearson product-moment correlation formula. In case of ties, the averaged ranks are used. Probability values for the Spearman correlation are computed by treating

$$t = (n-2)^{1/2} \left(\frac{r^2}{1-r^2} \right)^{1/2}$$

as coming from a t distribution with $(n-2)$ degrees of freedom, where r is the sample Spearman correlation.

Kendall's tau-b correlation coefficient is a nonparametric measure of association based on the number of concordances and discordances in paired observations. Concordance occurs when paired observations vary together, and discordance occurs when paired observations vary differently. PROC CORR computes Kendall's tau-b by ranking the data and using a method similar to Knight (1966). The data are double sorted by ranking observations according to values of the first variable and re-ranking the observations according to values of the second variable. PROC CORR computes Kendall's tau-b from the number of interchanges of the first variable and corrects for tied pairs (pairs of observations with equal values of X or equal values of Y).

(SAS, 2006)

Table 11 summarizes the results of performing the SAS PROC CORR function on the main Lean variables. The table shows significant correlation between the Lean Management System main variable (LMS) and the Lean Waste Reducing Techniques main variable (LWRT), and significant correlation between LWRT and the Lean Results main variable (LR).

Table 11. Correlation of Lean Main Variables

Simple Statistics						
Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
LMS	47	113.82979	14.06247	5350	79.00000	136.00000
LWRT	47	404.27660	36.27534	19001	288.00000	471.00000
LR	47	234.82979	18.14353	11037	185.00000	274.00000

Pearson Correlation Coefficients, N = 47
 Prob > |r| under H0: Rho=0

Variable Label	LMS	LWRT	LR
LMS LMS	1.00000	0.63618 <.0001****	0.26044 0.0771
LWRT LWRT	0.63618 <.0001****	1.00000	0.39812 0.0056**
LR LR	0.26044 0.0771	0.39812 0.0056**	1.00000

Significance *P<0.05 ** P<0.01 ***P<0.001 ****P<0.0001

Table 12 summarizes the results of performing the SAS PROC CORR on the main Green variables and controls. The table shows significant correlation between the Green Management System (GMS) main variable and the Green Waste Reducing Techniques (GWRT) main variable, and significant correlation between GWRT and the Green Results (GR) main variable. Thus, the two forms of validation (Cronbach alpha and Pearson correlation) suggest that although the data set is relatively small it is statistically strong. Thus, the data set is worthy of

further statistical analysis regarding the study's main hypotheses and other possible relationships within the data sets variables.

Table 12. Correlation of Green Main Variables

Variable	N	Simple Statistics				
		Mean	Std Dev	Sum	Minimum	Maximum
GMS	47	9.40426	4.62347	442.00000	1.00000	17.00000
GWRT	47	3.66474	0.62402	172.24274	1.78571	4.64286
GR	47	3.78457	0.54886	177.87500	2.80000	4.80000

Pearson Correlation Coefficients, N = 47
 Prob > |r| under H0: Rho=0

Variable Label	GMS	GWRT	GR
GMS GMS	1.00000	0.33442 0.0216*	0.19376 0.1919
GWRT GWRT	0.33442 0.0216*	1.00000	0.45715 0.0012**
GR GR	0.19376 0.1919	0.45715 0.0012**	1.00000

Significance *P<0.05 ** P<0.01 ***P<0.001 ****P<0.0001

Hypothesis Testing

The four main hypotheses are described in detail in Chapter 4: Methodology. For ease of reference they are restated with a detailed description of how each hypothesis was tested and the test results. Hypothesis I is unique in that it compares the environmental performance of the set of Shingo plants with the set of general manufacturers surveyed originally in the Melnyk study a few years earlier. The intent of this hypothesis is to show that known Lean manufacturers are exhibiting significantly higher levels of environmental practices and results than the general manufacturing population. This would show evidence of Lean manufacturers' transcendence to Green manufacturing.

Hypothesis I: Lean manufacturers, as recognized by the Shingo Prize team of examiners, are Greener than the general population of manufacturers, identified in the Melnyk study.

Hypothesis I, was tested by performing T-tests, utilizing the statistics available from the Melnyk study original data set and the Shingo data set for all twenty-six green variables surveyed. Table 13 shows the results of the T-Tests. Notice that for all three main variables and their respective sub-variables, the known Lean Shingo companies are significantly "Greener" than the general population of manufacturing plants. These strong results clearly indicate that Hypothesis I is true with a very high level of statistical significance.

Table 13. T-Test Results for Hypothesis I

Factor	Label	Melnyk			Shingo			Significance		
		N	Mean	SD	N	Mean	SD	t	p	Significance
ISO14001 certified	GMS1	1510	0.083		47	0.787	0.225			Meaningful difference
Years certified	GMS2	1510	0.917		47	3.574	2.842			Meaningful difference
Product redesign	GWRT1	1163	2.996	1.228	42	3.619	1.011	3.248	0.0012	**
Process redesign	GWRT2	1166	3.380	1.164	46	4.174	0.769	4.586	0.0000	****
Dissassembly	GWRT3	1155	2.612	1.208	42	3.024	1.239	2.168	0.0303	*
Substitution	GWRT4	1163	3.408	1.220	47	4.128	0.924	3.997	0.0001	****
Reduce	GWRT5	1160	3.328	1.212	46	3.978	0.830	3.605	0.0003	***
Recycling	GWRT6	1165	3.192	1.276	46	3.826	1.180	3.315	0.0009	***
Remanufacturing	GWRT7	1148	2.664	1.248	41	2.902	1.261	1.202	0.2297	
Consume Internally	GWRT8	1163	2.464	1.196	42	3.000	1.230	2.851	0.0044	**
Prolong Use	GWRT9	1154	3.004	1.592	44	3.545	1.170	2.233	0.0258	*
Returnable Packaging	GWRT10	1162	3.324	1.292	47	4.191	0.970	4.551	0.0000	****
Spreading Risks	GWRT11	1153	2.776	1.156	42	3.262	1.061	2.683	0.0074	**
Creating markets	GWRT12	1156	2.696	1.228	40	3.175	1.412	2.413	0.0160	*
Waste Segregation	GWRT13	1161	3.212	1.220	45	4.378	0.806	6.355	0.0000	****
Alliances	GWRT14	1154	2.984	1.220	47	3.723	1.057	4.092	0.0000	****
Reduced costs	GR1	1142	2.340	1.028	47	3.915	0.855	10.355	0.0000	****
Reduced lead-times	GR2	1143	2.084	0.912	42	3.095	0.821	7.081	0.0000	****
Improved product quality	GR3	1144	2.296	1.012	46	3.435	0.981	7.492	0.0000	****
Improved market position	GR4	1140	2.392	1.080	47	3.638	0.819	7.818	0.0000	****
Enhanced reputation	GR5	1144	2.940	1.236	47	4.298	0.623	7.490	0.0000	****
Improved product design	GR6	1144	2.440	1.108	45	3.622	0.886	7.068	0.0000	****
Reduced process waste	GR7	1144	2.892	1.196	47	4.191	0.798	7.380	0.0000	****
Improved equipment selection	GR8	1133	2.608	1.116	47	3.745	0.793	6.909	0.0000	****
Benefits outweigh costs	GR9	1138	2.684	1.132	46	3.935	0.680	7.438	0.0000	****
Improved international sales	GR10	1133	2.492	1.156	47	3.872	0.824	8.100	0.0000	****

Significance *P<0.05 **P<0.01 ***P<0.001 ****P<0.0001

Hypotheses II through IV are internally focused within the Shingo plants that responded to the survey. Respectively, these hypotheses relate to correlation between a plant's level of "Leanness" (LEAN) and its level of "Greenness" measured from the perspectives of the management system (GMS), waste reducing techniques (GWRT), and results (GR). The independent LEAN variable is the total score from the Shingo Prize Scoring system. The Green dependent variables are taken from the three sections of the survey, each being the average score for that section. For ease of reference the hypotheses are listed below followed by a description of how the hypotheses were tested and the results of these tests.

Hypothesis II: The overall Lean score (LEAN), as measured by the Shingo Prize examiners, positively correlates to the Green Management System score (GMS), as measured by the on-line Green survey.

Hypothesis III: The overall Lean score (LEAN), as measured by the Shingo Prize examiners, positively correlates to the Green Waste Reducing Techniques score (GWRT), as measured by the on-line Green survey.

Hypothesis IV: The overall Lean score (LEAN), as measured by the Shingo Prize examiners, positively correlates to the Green Results score (GR), as measured by the on-line Green survey.

Hypothesis II through Hypothesis IV were tested utilizing Pearson's product moment correlation coefficient tests and looking for probability (P-values) less

than 0.05 to determine significant correlation between the LEAN and GMS, GWRT, and GR. The control variables Quartile, Country, and Year were also included in the correlation matrix to determine if there was significant influence by these factors. The correlation matrix for testing hypotheses II – IV is shown below in table 14. Notice that P values less than 0.05 were not found between LEAN and GMS, GWRT, or GR, thus I was unable to prove these hypotheses statistically.

Table 14. Correlation Matrix for Hypotheses II - IV

Pearson Correlation Coefficients, N = 47
 Prob > |r| under H0: Rho=0

	Quartile	Country	Year	LEAN	GMS	GWRT	GR
Quartile Quartile	1.00000	0.12578 0.3995	-0.05906 0.6933	0.84040 <.0001****	0.08352 0.5768	0.11968 0.4230	0.16256 0.2750
Country Country	0.12578 0.3995	1.00000	0.12495 0.4027	0.05960 0.6907	0.20410 0.1688	0.38688 0.0072**	0.46051 0.0011
Year Year	-0.05906 0.6933	0.12495 0.4027	1.00000	-0.03004 0.8411	-0.21797 0.1411	-0.22244 0.1329	-0.17063 0.2515
LEAN LEAN	0.84040 <.0001****	0.05960 0.6907	-0.03004 0.8411	1.00000	-0.00534 0.9716	0.10754 0.4718	0.03308 0.8253
GMS GMS	0.08352 0.5768	0.20410 0.1688	-0.21797 0.1411	-0.00534 0.9716	1.00000	0.33442 0.0216*	0.19376 0.1919
GWRT GWRT	0.11968 0.4230	0.38688 0.0072**	-0.22244 0.1329	0.10754 0.4718	0.33442 0.0216*	1.00000	0.45715 0.0012**
GR GR	0.16256 0.2750	0.46051 0.0011**	-0.17063 0.2515	0.03308 0.8253	0.19376 0.1919	0.45715 0.0012**	1.00000

Significance *P<0.05 ** P<0.01 ***P<0.001 ****P<0.0001

Full Correlation and Regressions Analysis

Due to the fact that hypotheses II – IV could not be proven true, there was a desire to look more deeply into the sub-variables of the study to unearth any interesting findings. This analysis was conducted in two ways: First a full correlation analysis was performed using Pearson's product moment correlation coefficient on all main and sub-variables in the study. Of greatest interest for this study is the full correlation of all Lean variables and controls versus all Green variables. The second approach taken was to conduct regression analysis on all logical combinations of main variables on other main variables of the research model. This was an attempt to see if combinations of variables were strong predictors of other variables in the study.

Full Correlation Analysis

Table 15 shows the full correlation matrix for all Lean, Green and control variables. The letters "p" and "n" denote positive and negative correlations, respectively. The number of n's or p's denotes the level of significance (see bottom of table 15 for detail). Several interesting findings can be observed directly from this correlation matrix. These findings are organized along the left hand axis of table 15, in the following categories:

- Control variables
- Lean management system variables
- Lean waste reducing technique variables
- Lean result variables

Table 15. Full Lean and Green Correlation Matrix

		GREEN DEPENDENT VARIABLES FROM SURVEY																													
LABELS	VARIABLES	GMS1	GMS2	GMS	GWRT1	GWRT2	GWRT3	GWRT4	GWRT5	GWRT6	GWRT7	GWRT8	GWRT9	GWRT10	GWRT11	GWRT12	GWRT13	GWRT14	GWRT	GR1	GR2	GR3	GR4	GR5	GR6	GR7	GR8	GR9	GR10	GR	GREEN
		EMS/ISO14001 status	Years Certified	Total Green mngmt System	Product redesign	Process redesign	Disassembly	Substitution	Reduce	Recycling	Remanufacturing	Consume Internally	Prolong Use	Returnable Packaging	Spreading Risks	Creating markets	Waste Segregation	Alliances	Total Green Waste Reducing Techniques	Reduced costs	Reduced lead-times	Improved product quality	Improved market position	Enhanced reputation	Improved product design	Reduced process waste	Improved equipment selection	Benefits outweigh costs	Improved international sales	Total Green Results	Total Green score
CONTROL VARIABLES	Quartile	Quartile of "Lean" scores																													
	Country	Country plant located									pp		p		p	pp	pp	pp				p	p	ppp			pp		ppp	pp	pp
	Year	Shingo assessment year				nn		n		nn																					
LEAN INDEPENDENT VARIABLES FROM SHINGO PRIZE SCORING SYSTEM DATA BASE	IA	Leadership																					n								
	IB	Empowerment																													
	LMS	Total Lean Mngmt System																													
	IIA	Vision/Strategy		n																				n							
	IIB	Innovation								n	n								n												
	IIC	Partnerships		n	n	n		nn																							n
	IID	Operations																													
	III	Support functions	pp		p	p		p																	p						p
	LWRT	Lean Waste Reducing Techniques																						n							
	IVA	Quality	p																												
	IVB	Cost	ppp		p			pp						pp		p	pp		p								p				pp
	IVC	Delivery														p															
	v	Customer Satisfaction & Profitability							p				p			p	p														
	LR	LR	p						p						pp	p		p													
	LEAN	Total Lean score																						n							

Significance Positive (p)P<0.05 (pp) P<0.01 (ppp)P<0.001 (pppp)P<0.0001, Negative(n)P<0.05 (nn) P<0.01 (nnn)P<0.001 (nnnn)P<0.0001

Control variables

Control variable *Quartile* is the quartile that overall Lean score falls into from the lowest scores (Q1) to the highest scores (Q4). It was added to determine if there were differences between quartile groups of plants, as opposed to the continuous variable Lean. There were no correlations between Quartile and the Green variables.

Control variable *Country* significantly correlates to the main variables GWRT and GR, and logically to many of their sub-variables. The interesting finding here is that the country that is highly correlated to these Green practices and results is Mexico and not the United States. Specifically the Mexican plants show significantly higher adoption rates of the following Green waste reducing techniques and corresponding Green results:

- GWRT8: Consuming waste internally
- GWRT10: Use of returnable packaging
- GWRT12: Creating markets for waste
- GWRT13: Segregating waste
- GWRT14 Creating alliances
- GWRT: Overall adoption of Green waste reducing techniques
- GR3: Improved product quality
- GR4: Improved market position
- GR5: Enhanced reputation
- GR8: Improved equipment selection
- GR10: Improved international sales
- GR: Overall Green results

Control Variable *Year* indicates the year the Shingo assessment was performed.

Year correlates negatively and significantly to the following Green waste reducing techniques:

- GWRT1: Product redesign
- GWRT3: Disassembly
- GWRT5: Reduce

Lean Management System Variables

There was only one significant correlation between Lean management system variables and all of the Green variables on the study. Lean management system variable *Leadership (IA)* negatively and significantly correlated to Green results variable GR3: Improved product quality – as a result of Green efforts.

Lean Waste Reducing Technique Variables

There are several negative correlations between Lean waste reducing techniques (LWRTs) and sub-variables of GMS, GWRT, and GR. There are also several positive correlations between the LWRT variable *(III) Support functions* and Green variables in all three Green categories. Specifically the correlations regarding Lean waste reducing technique variables and the Green variables are listed below:

- IIA: Vision/Strategy negatively correlates to:
 - GMS2: Years of ISO14001 certification
 - GR3: Improved quality - as a result of Green efforts
- IIB: Innovation negatively correlates to:
 - Recycling (GWRT6)

- Remanufacturing (GWRT7)
- Alliances (GWRT8)
- IIC: Partnerships negatively correlates to:
 - Years of ISO14001 certification (GMS2)
 - Over all Green management system (GMS)
 - Product re-design (GWRT1)
 - Disassembly (GWRT3)
 - Total Green Score (Green)
- IID: Operations negatively correlates to:
 - Improved product quality, through green efforts (GR3)
- III: Support Functions positively correlates to:
 - ISO14001 certifications (GMS1)
 - Over all Green management system (GMS)
 - Product redesign (GWRT1)
 - Disassembly (GWRT3)
 - Enhanced reputation (GR5)
 - Total Green Score (GREEN)
- LWRT: Overall Lean waste reducing technique score negatively correlates to:
 - Improved quality (GR3), as a result of Green efforts

Lean Results Variables

There are many positive correlations between Lean results (LR) and GMS, GWRT, and GR. It is interesting to note that these Lean results were measured prior to the survey by the Shingo team, with no thought to environmental activities within the plant being examined. Specifically the correlations between Lean results variables and Green variables are as follows:

- IVA: Quality positively correlates to:
 - GMS1: ISO14001 implementation level
- IVB: Cost positively correlates to:
 - GMS1: ISO14001 implementation level

- GMS: Over all Green management system
- GWRT4: Substitution
- GWRT10: Returnable packaging
- GWRT12: Creating markets
- GWRT13: Waste segregation
- GWRT: Over all Green waste reducing techniques
- GR8: Improved equipment selection, by green efforts
- GREEN: Overall Green score
- IVC: Delivery positively correlates to:
 - GWRT12: Creating markets
- V: Customer satisfaction & Profitability positively correlates to:
 - GWRT4: Substitution
 - GWRT9: Prolong Use
 - GWRT12: Creating markets
 - GWRT13: Waste segregation
- LR: Overall Lean results positively correlates to:
 - GMS1: ISO14001 certification
 - GWRT4: Substitution
 - GWRT12: Creating Markets
 - GWRT13: Waste segregation
 - GWRT: Overall Green waste reducing techniques
- LEAN: Overall Lean score negatively correlates to:
 - GR3: Improved quality, as a result of Green efforts

The full correlation analysis yielded many interesting findings that will be discussed in Chapter six. There were several cases of both positive and negative correlations on similar sets of variables indicating the potential of confounding effects. This led to the use of more advanced analysis to identify multi-variant effects. Regression analysis was also performed on many of the variables in the data set and is presented below.

Multi-variant Regression Analysis

Initial review of the correlation data with committee members revealed that hypotheses II – IV, regarding main Lean and Green variables within the Shingo data set, were not proven. This led to conversation regarding multivariate effects within the model of combinations of Lean and Green variables on all other model variables. In order to understand the effects of multiple independent variables on a dependent variable, multi-variant regression analysis was performed using logical combinations of Lean and Green main variables as the independent variables and all individual main variables as the dependent variables. The SAS PROC REG function was utilized for this analysis. Regression analysis was performed on the following combinations of main variables from the Lean and Green research model in table 16. Model significance is summarized for each combination of independent variables with respect to the dependent variables.

Table 16. Multi-variant Regression Statistics

Dependent Variable	Independent Variables	Model Pr > F
GMS	LEAN, GREEN	<0.0001 ****
GMS	LMS, GWRT	0.0733
GMS	LMS, GR	0.4119
GMS	LWRT, GWRT	0.0666
GMS	LWRT, GR	0.4115
GMS	LR, GWRT	0.0735
GMS	LR, GR	0.3608
GWRT	LEAN, GREEN	<0.0001 ****
GWRT	LMS, GMS	0.0697
GWRT	LMS, GR	0.0046 **
GWRT	LWRT, GMS	0.0668
GWRT	LWRT, GR	0.0053 **
GWRT	LR, GMS	0.0145 *
GWRT	LR, GR	0.0010 ***
GR	LEAN, GREEN	0.0002 ***
GR	LMS, GMS	0.3814
GR	LMS, GWRT	0.0045 ***
GR	LWRT, GMS	0.4306
GR	LWRT, GWRT	0.0056 **
GR	LR, GMS	0.3963
GR	LR, GWRT	0.0053 **
LMS	LEAN, GREEN	<0.0001 ****
LMS	GMS, LWRT	<0.0001 ****
LMS	GMS, LR	0.1967
LMS	LWRT, GWRT	<0.0001 ****
LMS	LR, GWRT	0.1364
LMS	LR, GR	0.2028
LWRT	LEAN, GREEN	<0.0001 ****

Table 16. (Continued)

LWRT	GMS, LMS	<0.0001 ****
LWRT	GMS, GR	0.0182 **
LWRT	LMS, GWRT	<0.0001 ****
LWRT	LMS, GR	<0.0001 ****
LWRT	LR, GWRT	<0.0198 *
LWRT	LR, GR	0.0212 *
LR	LEAN, GREEN	<0.0001 ****
LR	GMS, LMS	0.1588
LR	GMS, LWRT	0.0151 **
LR	LMS, GR	0.1942
LR	LWRT, GR	0.0185 **
LR	LWRT, GWRT	0.0032 **
LR	LMS, GWRT	0.0229 *

Generally speaking, for each of the regression combinations, model significance (P value) was influenced solely by the independent variables from the same manufacturing system as the dependent variable. That is to say, the Lean independent variables in the model influenced model significance for Lean dependent variables, and Green independent variables influenced model significance for Green dependent variables. This is evident by the lack of significant P values for the predictor variable not from the same manufacturing system as the dependent variable.

However, in two cases both the Lean and Green independent variables were significant, as well as the overall model, for the dependent variable LR (Lean results). In both cases, the Green independent variable was GWRT (Green

waste reducing techniques). The Lean independent variables were LMS (Lean management system) and LWRT (Lean waste reducing techniques). These results indicate with a high level of significance that GWRT and LMS, and GWRT and LWRT are strong predictors of Lean results (LR).

Interestingly, GWRT had a substantially higher P value than LMS, indicating that Green waste reducing techniques is a stronger predictor of Lean results than the Lean management system. This surprising result will be discussed further in chapter 6. Given the significance of these findings, the regression outputs for these two cases are listed below in tables 17 and 18.

Table 17. Regression Results of LR with GWRT and LWRT Predictors

The REG Procedure

Model: MODEL1
 Dependent Variable: LR LR

Number of Observations Read 47
 Number of Observations Used 47

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	3474.20587	1737.10294	6.55	0.0032
Error	44	11668	265.19165		
Corrected Total	46	15143			

Root MSE 16.28471 R-Square 0.2294
 Dependent Mean 234.82979 Adj R-Sq 0.1944
 Coeff Var 6.93468

Parameter Estimates

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > t
Intercept	Intercept	1	128.41259	29.79103	4.31	<.0001
GWRT	GWRT	1	7.75204	3.85183	2.01	0.0503
LWRT	LWRT	1	0.19296	0.06626	2.91	0.0056

Table 18. Regression Results of LR with GWRT and LMS Predictors

The REG Procedure						
Model: MODEL1						
Dependent Variable: LR LR						
		Number of Observations Read		47		
		Number of Observations Used		47		
Analysis of Variance						
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	
Model	2	2388.40054	1194.20027	4.12	0.0229	
Error	44	12754	289.86904			
Corrected Total	46	15143				
		Root MSE	17.02554	R-Square	0.1577	
		Dependent Mean	234.82979	Adj R-Sq	0.1194	
		Coeff Var	7.25016			
Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > t
Intercept	Intercept	1	162.05991	25.93854	6.25	<.0001
GWRT	GWRT	1	8.73196	4.02934	2.17	0.0357
LMS	LMS	1	0.35816	0.17880	2.00	0.0513

Chapter Summary

This concludes the Data Analysis and results chapter. The analysis and results presented in this chapter will be discussed in detail in the following chapter six.

Chapter Six

Discussion of Results

Introduction

Since the 1990's researchers have set out to better understand the relationship between Lean and Green manufacturing systems, given that both systems focus centrally on the elimination of waste. This dissertation contributes to the Lean and Green body of knowledge by determining if Lean manufacturers adopt Green manufacturing system best practices. To restate the research question: Do Lean manufacturers transcend to Green manufacturing?

The population of known Lean manufacturing plants (Shingo) was compared to the general population of manufacturing plants (Melnyk), as stated in hypothesis I. The results are clear that Lean plants adopt significantly higher levels of Green manufacturing best practices than the general population. Yet, when comparing adoption levels of Green manufacturing best practices at a high level within the Shingo plant population, as identified in hypotheses 2 – 4, the results are inconclusive. This is very much the result of comparing best practice variables at a categorical (main variable) level between Lean and Green systems.

However, full correlation and regression of the sub-variables that constitute the main Lean and Green variables of the study yield strong evidence of not only

transcendental behavior, but that synergy exists between Lean and Green manufacturing systems. Specifically, Green best practices positively correlate to both Green and Lean results at the sub-variable level. Analysis also yielded some interesting findings related to plant's choice to vertically or horizontally integrate its Lean systems and the dichotomous correlation this had to Green system variables. There are indications that a myopic focus on Lean at the management system and strategic levels may detract from transcendence to Green manufacturing, and perception of Green results. There were also some rather counter-intuitive findings related to the country of plant location, all of which are described in detail below.

Validation of Data Discussion

The data sets for the study were validated in two ways, first by performing the Cronbach reliability tests and secondly by reproducing the results of early studies regarding the relationship of the main variables to each other. The Cronbach test showed high levels of reliability, thereby indicating that the data sets, albeit small, were statistically powerful and worthy of correlation and regression analysis. The more interesting result was how I was able to reproduce the findings of earlier research regarding the relationship of the management system to the implementation of waste reducing techniques and their relationship to results.

Melnyk et. al. (2003), were able to prove that the Green Management System (i.e. ISO14001) strongly correlated to the Green waste reducing techniques and that the Green waste reducing techniques strongly correlated to Green results,

with the same survey instrument utilized in this dissertation study. As shown in table 12 of chapter five, the results were reproduced for the forty-seven Shingo plant data set, which was much smaller than the roughly eleven hundred plant data set from the Melnyk et. al. study. This is very strong validation that the data set for this study holds sufficient statistical power.

Similar results were found regarding the relationship between the Lean variables LMS, LWRT and LR. That is to say, table 11 shows significant correlation between the Lean management system (LMS) and Lean waste reducing techniques (LWRT), and significant correlation between LWRT and Lean results (LR). Unfortunately, there is no previous study that utilized the exact same criteria to produce these results originally, as was done for the Green study (Melnyk et. al., 2003). However, all leading models of the Lean manufacturing system specifically indicate the critical importance of the Lean management system creating the environment for Lean waste reducing techniques to take hold, and the how results only come from continuous implementation and sustaining of Lean waste reducing techniques. (Liker, 2004) (Shingo, 2003) (SME, 2006).

Hypothesis Testing Discussion

Hypothesis I was unique in that it compared the Green survey statistics of the entire Shingo plant survey respondents to the statistics of the general population of manufacturing plants surveyed originally by Melnyk et. al. (2003). As described in detail in Chapter 4: Methodology, Melnyk et. al. took extraordinary

care to assure that the population chosen for their survey was based on accepted industry data bases of manufacturers and filtered to assure they were discrete manufacturers, in sectors likely to implement environmental management systems.

It is therefore reasonable to assert that the “Melnyk” population represents the general population of manufacturing plants for comparison to the Lean Shingo plants. It is also reasonable to assert that the Shingo plants represent the known Lean population, given that all earned the distinction of receiving site visits from Shingo examiners, and received high scores on the Shingo scoring system index. As described in the methodology chapter of this dissertation, all Shingo plants are discrete manufacturers, as required in the Shingo application criteria, and industry sectors where ISO14001 is common. All of this is stated to assure an “apples to apples” comparison between the Shingo plants and Melnyk plants.

Hypothesis I Findings

The T-test analysis (table 13) for hypothesis I provides strong statistical evidence that the known Lean Shingo companies are significantly greener than the general manufacturing population. In twenty-five of the twenty-six measures of Greenness the Shingo companies are significantly Greener, at $P < 0.05$ level of significance. In looking closely at table 13 it shows the T-test results of Shingo versus Melnyk statistics, it can be observed that in many cases (19 out of 26) the significance level is $P < 0.01$.

Notice for the Green results (GR) section, variables GR1 through GR10, that in all cases the significance is $P < 0.0001$, the highest practical level of statistical significance. The significance level of the Green results section is disproportionately higher than the significance levels for the Green waste reducing techniques (GWRTs). Yet, we know that the GWRTs strongly correlate to GR variables. This suggests that Lean plants that implement Green waste reducing techniques are realizing disproportionately better results of their Green efforts than the general population. This suggests there may be synergy between Lean and Green efforts within the Shingo plants. That is to say, plants that commit themselves to Lean best practices, not only realize strong Lean results, they also realize better results from their Green best practices than the general population.

The logical explanation for this finding is that Lean plants have a well-honed infrastructure for identifying and eliminating waste, through total employee involvement and continuous improvement. If Green wastes were identified as opportunities for improvement, the efficiency by which Lean plants would reduce these waste, and generate measurable Green results, would logically be much higher than a plant without the Lean culture. Often is the case in non-Lean plants that “band-aid” solutions are deployed to address an environmental symptom. Lean plants possess a disciplined approach to problem solving that gets to the root cause of the problem efficiently and implement systemic solutions that yield sustained results.

The findings of this hypothesis alone provide strong evidence of transcendence to Green manufacturing by leading Lean manufacturers. It is clear from the statistics that the level of adoption of both Lean and Green best practices are very high across the board for the Shingo companies. This is clear evidence that Lean companies are implementing Green manufacturing systems. This suggests that they may be taking a holistic view of waste elimination that includes both Lean and Green wastes. The findings also suggest evidence of synergy between the two systems.

Hypothesis II – IV Findings

Hypotheses II-IV were more inwardly focused than hypothesis I. These hypotheses sought to determine if higher levels of Leanness among the Shingo plants correlated to higher levels of Greenness within the same Shingo population of survey respondents. As indicated in Chapter 5, no significant correlation was found between higher overall levels of Leanness (LEAN) and the three main variables for the Green manufacturing system; Green Management System (GMS), Green waste reducing techniques (GWRT), and Green results (GR). These findings were disappointing, because they did not support the findings of hypothesis I that showed such significant difference in Green variables between the known Lean Shingo plants and the general manufacturing population.

Perhaps the convenient explanation for the lack of statistical significance between Lean scores and Green scores is that we are dealing with all Lean

plants, and perhaps splitting hairs. It took a panel of five Lean experts from the Shingo team to perform thorough evaluation of these plants to come up with different Lean scores. It could be that there are such subtle differences between their Leanness, it does not reflect in the high measures of Greenness. Of course, the fact that there is sufficient stratification of data within the Shingo set to show significant correlation between the main variables (LMS, LWRT, and LR) challenges the “splitting hair” theory.

The alternative theory is that there may be a limit, or zero sum gain, to the amount of improvement activity that a company can commit to and execute at any point in time. Melnyk et. al. (2003) and Florida (1996) observed that the size of the company, and hence the size of the resource pool, significantly correlated to the level of environmental practices. Ideally, the “zero sum gain” theory should have born out statistically by showing reverse correlation between the main Lean and Green variables. Interestingly, it was found that the plant that scored the highest overall GREEN score had the lowest overall LEAN score. But this was just one data point, and reverse correlations for the entire Shingo data set were not found for the main variables.

With no strong positive or negative correlations to report, it became evident that the high-level statistics (main variable correlations) where not telling the whole story. This led to speculation that there was something going on at the sub-variable level that warranted further analysis. Perhaps several sub-variable positive and negative correlations were canceling each other out when viewed at

the high-level. This led to extensive analysis at the sub-variable level during the summer months, the results of which are discussed below.

Full Correlation Analysis Discussion

Full correlation analysis was performed for all main variables and sub-variables in the study (i.e. Lean, Green, and control variables). Table 15 shows the matrix of Lean & control variables from the Shingo prize database as row headings and Green variables obtained from the survey as column headings. Several interesting correlations can be observed directly from this matrix, some of which are counter-intuitive. For simplicity this discussion is organized by the categories of the Shingo prize variables (row headings on the left side of table 15). Their correlations to the Green variables are contained within each section, specifically:

- Control variables
- Lean Management System
- Lean Waste Reducing techniques
- Lean results

Control Variable Findings

Quartile

Control variable *Quartile* is the quartile of overall Lean scores that a plant falls into by breaking the data set into quarters. The score of (1) was applied to the lowest quartile LEAN scores and the score of (4) was applied to the highest quartile LEAN scores and scores of (2) and (3) for the second and third quartiles

respectively. The decision to introduce the Quartile control variable was intended to determine if blocks of Lean plants showed significant difference in Green scores, since the continuous variable LEAN did not show any correlation for the main hypotheses variables of GMS, GWRT, and GR. Quartile, similar to the continuous variable LEAN, did not show any correlation to any of the Green scores, thus reinforcing the point that the overall or macro perspective when comparing Lean and Green performance is non-indicative.

Year

Control variable *Year* measures the year the site visit was conducted by the Shingo examiners who generated the set of Lean scores in the Shingo database. The expert opinion is that Lean plants, as a function of their continuous improvement culture, continue to become “Leaner” over time from the point they were assessed. It is important to clarify that *Year* is the calendar year the site visit was conducted and it might have made more sense to define this variable as “years since site visit was conducted”. Thus, a negative correlation actually suggests a positive finding. The statistics reflect a negative correlation between the control variable *Year* and three Green waste reducing technique variables, *Product design*, *Disassembly*, and *Reduce*.

Given the assumption that a plant continues to get leaner over time, as suggested by the Shingo experts, a lower score in *Year* suggests that the Lean scores are slightly lower than they would be if the plant were measured today. Thus, the inverse correlation implies that the plants with older Lean scores are

showing significantly higher Green scores relative to their Lean scores, which may be slightly understated. This could suggest that over time these plants became both Leaner and Greener, which supports the overall hypothesis of the study. It would be interesting to perform a longitudinal study on these plants to better understand the changes in Leanness since first measured by the Shingo examiners.

The problem with this finding is there are so many assumptions. It could be argued that since the five year period when Shingo score were obtained coincided with a major economic downturn (i.e. 9/11/2001), that these plants actually were forced to reduce Lean efforts and cut back resources. This would suggest they could have been less Lean today than when they were measured.

Conversely, Lean literature indicates that what makes Lean companies great is how they stick to their commitment to Lean even during the toughest times (Shingo, 2003). During economic downturns, Lean companies send idle workers to advanced training or focus them on process improvement, while non-Lean companies simply lay-off employees. As a result, when the economy picks up again, Lean companies tend to “leap-frog” their non-Lean competitors. Toyota is a classic example of this strategy as they have successfully been “leap frogging” other automakers for years this way. Toyota maintains billions in cash reserves to buoy employees during difficult times, so as not to lose the investment they make in their people. (Liker, 2004)

Country

Control variable *Country* correlates positively and significantly to overall Green waste reducing techniques (GWRT), Green results (GR), and their sub variables. As mentioned previously, the counter-intuitive finding is that the Mexican plants were significantly higher than the US plants in many Green waste reducing technique (GWRT) and Green result (GR) categories. To refresh the reader, the positive correlations related to Mexican plants are as follows:

- GWRT8: Consuming waste internally
- GWRT10: Use of returnable packaging
- GWRT12: Creating markets for waste
- GWRT13: Segregating waste
- GWRT14: Creating alliances
- GWRT: Overall adoption of Green waste reducing techniques
- GR3: Improved product quality
- GR4: Improved market position
- GR5: Enhanced reputation
- GR8: Improved equipment selection
- GR10: Improved international sales
- GR: Overall Green results

The Shingo Prize is available to manufacturers in North America, thereby including plants from Mexico and Canada, in addition to the US. (Note: Ten Mexican plants were in the sample, yet no Canadian plant responded to the survey). The set of significantly higher Green waste reducing techniques that the Mexican plants employ paints a picture of material resourcefulness and collaboration. Let's revisit the complete description of each of these significant GWRTs from the Green survey.

- GWRT8 (Consume internally): Consuming waste internally (e.g. wood pallets used in shipping or product storage used to generate electrical power in co-generation facility)
- GWRT10 (Returnable packaging): Using packaging and pallets that can be returned after they are finished being used
- GWRT12 (Creating markets - for waste products): Treating waste as an input to another product which can be made and sold at a profit
- GWRT13 (Waste Segregation): An intermediate action in which waste streams are separated out into their individual components before being recycled, reused or consumed internally
- GWRT14 (Alliances): Working with either suppliers or consumers to address environmental problems and/or issues

Together the waste reducing techniques imply that these plants go to great lengths to conserve material resources. It is rather easy to visualize a process by which waste streams are being separated in components for reuse, recycling, or internal consumption. Reusable packaging is returned to suppliers, perhaps as a kan ban signal for replenishment. Waste that can be consumed internally is burned to create energy for the facility. Markets are established to sell process by-products that can be used in processes of other local manufacturers. Alliances are formed with suppliers and customers to discuss better ways to conserve resources and reduce environmental impact.

The picture painted by these significant GWRTs seems to imply a resourceful culture where there is a natural tendency to utilize all that can be utilized prior to dumping it into landfills, which may also be limited in availability. In contrast to this picture of the Mexican industrial community is the picture of the US manufacturing plant. The US has massive infrastructures for providing raw materials and disposing of wastes that may seem on the surface more efficient than reusing or reprocessing byproducts.

These findings also imply a close-knit industrial community in Mexico, where suppliers, manufacturers and even consumers are part of an industrial community. This seems similar to the industrial parks of Japan (i.e. Toyota City), where suppliers are located close enough to manufacturers to provide Just-in-time shipments, an essential element of the Lean system. Close proximity would facilitate both the selling of waste products as inputs to other plants and forming alliances. Perhaps there is also more of a cultural tendency to work together as a community in Mexico than in the US. In contrast, plants in the US seem rather spread out along our vast landscape so it may not be as logistically practical to return packaging or sell and deliver waste products to other plants.

The US culture is also known for individual behavior that may not lend itself as much to forming alliances to address environmental issues. The US also has the dubious distinction of being the most wasteful society, where the average US citizen generates one hundred times the waste of someone in the third world (Prokop, 1993). Given all of these factors, it is now logical to see how the Mexican plants are significantly higher in the five specific GWRT sub-variables and the overall GWRT main variable.

The significant difference in Green results (GRs) amongst Mexican plants is not surprising given that the Mexican plants exhibited higher adoption rates of Green Waste Reducing Techniques. This is consistent with the correlation analysis performed on the main Green variables for the overall data set. Specifically, the Green results variables where the Mexican plants were significantly higher than

the US plants are listed below, with their full survey definition for further discussion:

- GR3: Significantly improved product quality (as a result of Green efforts)
- GR4: Significantly improved position in the market place
- GR5: Helped enhanced the reputation in the market place
- GR8: Significantly reduced waste within the equipment selection process
- GR10: Improved chances of successfully selling its products in international markets.
- GR: Overall Green results

Improved quality speaks to how the techniques used to reduce material waste in a process are the same used to improve product yield and hence quality (this is addressed later in the chapter). Improved market position, enhanced reputation in market place and improved international sales address the positive effects the Mexican plant's Green efforts have on the market place.

There are growing requirements that sub-contractors to major manufacturers or entire countries must assure sound environmental practices in order to ship product to that company or country. This is true for ISO14001 certified companies that must commit to doing business with environmentally conscious partners and for the European Union who recently passed trade restrictions that require any electronics manufacturer shipping product to the EU must assure they are lead free (ROHS, 2006). This may be quite a competitive differentiator for Mexican plants that embrace Green practices for potential customers with strong environmental policies.

It should be noted that the Mexican plants in this study may be “transplants” from US Corporations that probably require sound environmental practices in order to comply with their ISO14001 certification requirements or corporate policy to assure a positive public image. This would serve as a starting point and/or catalyst for the Mexican plants’ environmentally conscious behavior.

It is also likely that these plants are newer than domestic plants in the study, for reasons of expansion or outsourcing to lower labor cost markets. The fact that Mexican plants show significant results in the equipment selection variable suggests that they may have taken advantage of modern technology that is more environmentally friendly. The Rothenburg study of automotive plants, cited in the literature review, found that legacy plants had lower levels of environmental performance than newer plants and argued that this was due to older technology that is generally less environmentally conscious and resource efficient.

(Rothenburg et. al. 2001)

Lean Management System Findings

Curiously, there was only one correlation between the entire category of Lean management system and all Green variables, and it was negative. Specifically, *Leadership* significantly and negatively correlated to the *improved product quality – as a result of Green efforts*. To better understand this relationship, it is helpful to state the definition of these variables from the Shingo criteria and the Green survey:

IA. Leadership

This subsection is designed to evaluate leadership at all levels of an organization with regard to application of world-class strategies and core business system practices that drive world-class results. Leadership creates an organizational culture and infrastructure that aligns the company's mission, strategy and policy to deploy lean/world-class practices and achieve world-class results.

Please discuss how your organization uses leadership to deploy world-class and lean strategies and practices to achieve world-class results. Examples of the items that could provide evidence in this section include, but are not limited to:

- Statements of vision, mission, values, strategies and goals
- A planning process for establishing and deploying vision, mission, values, strategies and goals (e.g., Hoshin Kanri, Policy Deployment, Management By Objective, etc.)
- Allocation of resources for deploying vision, mission, values and strategy
- Sustained personal commitment and involvement of all the organization's managers to find and eliminate waste (muda), or any non value-added activities and costs
- Knowledge management system and business results that are deployed to all levels of the company
- Communication and measurement of quality, cost and delivery standards throughout the organization
- An organizational philosophy that encourages and recognizes innovations, entrepreneurship and improvements wherever they originate in the organization

(Shingo, 2003)

- GR3: Significantly improved product quality

The only rational explanation for this negative correlation is that presence of a comprehensive Lean management system implies a very strong focus by senior management on the implementation of Lean waste reducing techniques and measurable results. One of the major performance measures of Lean is "Quality". This finding may suggest a bias on the part of the plant, in an effort to show success of the Lean system, to associate all quality improvements with the lean system, and to discount the contribution of Green efforts towards quality

improvement. To the degree that a plant had integrated its Lean and Green management systems, it becomes more difficult to determine how much quality improvement is due to Green efforts.

Lean Waste Reducing Technique Findings

There are several negative correlations between Lean Waste Reducing Techniques (LWRTs) and Green main and sub-variables. Yet there are positive correlations between *support functions* and several Green variables. Curiously, *support functions* and *Partnerships* exhibit equal but opposite correlations to nearly the same set of Green variables. These relationships will be discussed categorically relative to each LWRT sub-variable in the following order:

- IIA - Vision and strategy (IIA)
- IIB - Innovation
- IIC - Partnerships
- III - Support functions
- IID - Operations
- LWRT – Overall Lean waste reducing techniques

Vision and Strategy

Lean *vision and strategy* significantly and negatively correlates to *years ISO14001 certified* and *Improved quality – as a result of Green efforts*. To better understand these relationships, it is helpful to state the full definition of these variables from the Shingo criteria and the Green survey:

IIA. Manufacturing vision and strategy

This subsection requires an outline of the company's manufacturing vision and strategy as it relates to the selection and use of the specific methods, systems and processes detailed in subsections B, C, and D of this section. (Shingo, 2003)

- GMS2: Number of years the plant's Green management system has been ISO14001 certified
- GR3: Significantly improved product quality

This finding is consistent with negative correlation between Lean *leadership* and *improved quality*. The fact that *vision and strategy* also negatively correlates with *years ISO14001 certified*, indicates that while these plants have well established visions and strategies for their Lean system, they are in their infancy regarding their Green systems vision and strategy. Together, these negative correlations make the point stronger that a myopic focus on Lean at the strategic level detracts from management commitment to Green and perception of the benefits of the Green system.

This finding may suggest a bias on the part of the plant, to associate all quality improvements with the Lean system, and to discount the contribution of Green efforts towards quality improvement. This suggests that awareness of the complementary natures of Lean and Green systems at the executive level is essential for their integration and resulting synergistic benefits.

Innovation

Lean waste reducing technique variable IIB (innovation) negatively and significantly, correlated to Green waste reducing technique variables *Recycling*, *Remanufacturing*, and *Alliances*. To better understand these relationships, it is

helpful to state the definition of these variables from the Shingo criteria and the Green survey:

IIB. Innovations in market, service and product

This subsection is designed to evaluate a company's market service and product innovation. Any available information regarding competitors' benchmarking of services and products should be included. Two potential approaches could be pursued: (1) innovative efforts to reduce the cost of existing product(s) and product development; and (2) innovations in market service. Both approaches are viewed as enhancing business growth and performance. The second approach generally applies to companies that are primarily assemblers or those who manufacture a commodity-type product with limited opportunity for new product development.

The methods and processes documenting market service and product innovation may include, but are not limited to:

- Verifiable cost reductions in logistics, sales, service, post sales service, technical support, etc. for an assembler or a manufacturer of a commodity product
- Using quality function deployment, concurrent or simultaneous engineering, etc. for product development
- Benchmarking competitors' products and services
- New market development and current market exploitation
- Design for manufacturability, testing, maintenance, assembly, etc.
- Variety reduction
- Converting a commodity-type product to a more specialty differentiated product
- Innovations in market service and logistics
- Broadening sales mediums to include avenues such as e-commerce, the internet, etc.

(Shingo, 2003)

- GWRT6 (Recycling): making more use of recycled components or making a product which is more easily/readily recycled
- GWRT7 (Remanufacturing): restoring used durable products to "new" condition, to be used in their original function, by replacing worn or damaged parts
- GWRT14 (Alliances): working with either suppliers or consumers to address environmental problems and/or issues.

This finding also speaks to the notion that a strong lean focus regarding product and market innovations may create myopia toward Green. This result also speaks to the matter of limited resources. That is to say, as long as the disciplines of Lean and Green product innovation are considered unique and not integrated, it would be difficult to simultaneously support separate design efforts from a resource perspective.

Partnerships

Partnerships negatively and significantly correlates to *Years ISO14001 certified, overall status of the Green management system, Product design, Disassembly, and the overall Green score*. To better understand these relationships, it is helpful to state the definition of these variables from the Shingo criteria and the Green survey:

IIC. Partnerships with suppliers/customers and environmental practices

This subsection is designed to evaluate the company's efforts to deploy world-class practices by partnering with suppliers and customers, and to assess how well the company integrates suppliers and customers into the value-creation process. Discuss how your organization uses partnering to deploy world-class practices and/or to achieve world-class results.

Documentation in this section may include but is not limited to:

- The integration of the company, its suppliers and its customers in establishing value-creating methods and practices across company boundaries in production or product development
- Distribution and transport alliances to insure product quality and productivity
- Initiatives regarding environmental issues (i.e., recycling, reducing industrial waste, ISO 14000, etc.)
- Supplier satisfaction measures
- Union partnership initiatives
- Benchmarking projects for process improvement.
- Cooperative endeavors with schools and training organizations to ensure a qualified workforce
- Cooperative community endeavors that demonstrate the company and its employees are socially responsible

(Shingo, 2003)

- GMS2 (Years certified): Number of years the plant's Green management system has been ISO14001 certified
- GMS (Overall GMS status): Overall status of Green management system, implementation status and years certified.
- GWRT1 (Product redesign): redesigning the product to eliminate any potential environmental problems (manufacturing or recycling)
- GWRT3 (Disassembly): redesigning the product or process so as to simplify disassembly and disposal at the end of the product's useful life
- GREEN: Overall survey score

From the description, Partnerships speaks to the breadth versus the depth of the Lean system implementation. It is an overall measure as to how the plant has disseminated its Lean practices out to its broader "value chain" of suppliers and customers. This is an external versus internal focus, also described as a "horizontal integration" versus "vertical integration" of the plant's lean system, respectively. With the amount of resources it takes to integrate and improve external processes, it would be no surprise that it would detract from resources for going deeper into the internal processes to implement Green system elements. Let's explore these relationships categorically.

The fact that Partnerships negatively correlates with the Green management system variables supports the notion that these particular companies are more externally focused on Lean waste elimination than expanding their internal Lean waste reducing efforts to include Green practices. These plants may have chosen to outsource environmentally challenging processes to supply chain partners, thus avoiding the need to implement Green solutions.

The Green management system is the strongest indicator to a plant's overall commitment to the Green system. It drives Green waste reducing techniques and results, as indicated in the Melnyk study (2002) and confirmed in the data validation table 12. It then follows logically that if Partnerships negatively correlates with Green management system, it also correlates negatively to the overall Green score. This is perhaps yet another form of validation of how critical the Green management system is to the overall Green system.

From the expanded survey description Product redesign and Disassembly are both direct indicators of a plant's product design capabilities. Having an internal design team that is extensive enough to consider advanced environmental aspects in its product design, may be indicative of vertical integration. If so, this would be consistent with the inverse correlation with partnerships that is a measure of horizontal integration. Perhaps these plants outsource their product design to one of their value chain partners where emphasis may lie mostly on fulfilling specific Lean objectives.

Curiously though, this variable also measures "initiatives regarding environmental issues", and in particular ISO14001. It is counter-intuitive that this would result in a negative correlation to several Green variables, in particular, Overall Green management system and Years certified that are direct measures of ISO14001 implementation! There is perhaps a logical explanation for this and it has to do with the weight the Shingo examiners place on the environmental element of this variable.

When I first spoke to Dr. Ross Robson (Executive director of the Shingo Prize) regarding the use of the Shingo criteria as my independent variables, I voiced concern about the fact that they were already measuring some “Green” elements and this may bias the results. He indicated that the weight currently applied to this particular variable was negligible and the main focus was on the Lean enterprise elements. He then went on to say that it was essentially a place holder that one day, perhaps as a result of my research, may be fleshed out and have more weight applied to it.

Hopefully, my research will indicate the Green practices complementary to the Lean system, which could be woven into this category of the Shingo criteria. I do think that environmental considerations are currently mis-placed in the partnership category and should reside in the support functions category of the Shingo criteria.

Support Functions

Next we will discuss the positive correlation between *Support functions* and the set of Green variables *{Status of Green management system implementation, Overall Green management system, Product redesign, Disassembly, Enhanced reputation, and Total Green score}*. Let’s begin with the detailed definition of these variables from the Shingo Prize criteria and the Green survey:

III Non-manufacturing support functions

This section is designed to evaluate (1) the degree of integration between manufacturing and all non- manufacturing functional units; and (2) the extent to which improvement techniques and strategies have been applied in non-manufacturing functions up and down the value stream (new product development efforts are detailed in Section IIB and need not be repeated here). Non-manufacturing support functions may include

accounting, finance, human resources, sales and marketing, materials, purchasing, quality, MIS, etc. Address only those non-manufacturing functions that fall under the scope or control of the applicant site.

Evidence could include, but is not limited to, a discussion of:

- Alignment of non-manufacturing functions to support the manufacturing function
- The integration of non-manufacturing functions with manufacturing
- Incorporation of continuous improvement in the mission or vision

statements, goals or strategies of all non-manufacturing functions

- Elimination of waste or non-value-added activity in all functional units of the organization (e.g., closing of financial books in hours rather than days)
- Commitment to continuous improvement projects and/or change processes in long-range plans, capital budgets, training and human resource development, marketing plans and strategic reviews by all functional business units

(Shingo, 2003)

- GMS1 (Status of GMS): Status of plants Green management system implementation.
- GMS (Overall GMS status): Overall status of Green management system, implementation status and years certified.
- GWRT1 (Product redesign): Redesigning the product to eliminate any potential environmental problems (manufacturing or recycling)
- GWRT3 (Disassembly): Redesigning the product or process so as to simplify disassembly and disposal at the end of the product's useful life
- GR5 (Enhanced reputation): Helped enhance the reputation of your company
- GREEN: Overall survey score

From the detailed description of *support functions*, it is clearly a measure of internal or vertical integration of the Lean system. The definition for support functions describes close knit integration of non-manufacturing support groups and manufacturing to continuously eliminate waste in all facets of the business. This suggests holistic view of waste minimization throughout all plant functions. Perhaps as all plant functions become enlightened to waste elimination, this

translates to environmental waste elimination. After all, waste in any form is still waste.

Identified in the Green literature review are many examples of the importance of support functions to the overall success of the Green system. For example, both Lean and Green literature emphasize the importance of Activity based (or Total Cost) Accounting to account for waste in the product cost, so that it stands out as an opportunity for cost reduction (see literature view for details). This is in contrast to traditional standard based cost accounting that hides these costs in overhead or worse yet categorizes them as assets (i.e. inventory). It is logical that accounting practices implemented to support Lean manufacturing would also support Green manufacturing.

Another good example is how materials groups and logistics groups are critical to support Lean and Green initiatives. If a plant has a strong materials and purchasing team that is looking for suppliers to support the elimination of Lean wastes in the supply chain, they could easily undertake the elimination of environmental wastes as well, by assuring that less hazardous materials were purchased for example. The same can be said for a logistics support department that seeks to reduce the distance and create pull/kan ban systems to support the JIT principles of the Lean system. This directly supports several Green waste reducing techniques, such as returnable packaging, disassembly, and remanufacturing that rely on a strong logistics infrastructure.

I believe it is fair to say, based on the literature review, that Lean and Green systems/strategies depend on strong support functions to create an infrastructure for broad based waste elimination. The significant correlation between Lean variable III (Support functions) and Green variables in the GMS, GWRT, GR categories, and most strikingly the overall Green score, offers sound statistical evidence that the plants that have taken a holistic approach to Lean, are also taking a holistic approach to Green. The generalized conclusion that can be drawn from this finding is that as the Lean waste elimination culture spreads throughout the plant, it leads to *transcendental* behavior to seek out and eliminate Green wastes. In the literature review, Panizzolo speaks to how vertical integration of Lean practices precedes horizontal integration amongst leading Lean manufacturers. (Panizzolo, 1998)

There is a saying that Dr. Jeffery Liker (2004) uses regarding successful deployment of the Lean system. And, that is “it is best to go an inch wide and a mile deep”. The point here is that for the Lean system to sustain, it takes a laser like focus on a particular process and team to culturally ingrain the Lean system. Spreading the deployment of the Lean system too quickly throughout the plant or the extended enterprise can result in an unsustainable system, as the culture reverts back to the old habits. This would explain why the plants that chose to go deep instead of wide, sought out additional Green waste reducing practices. They were compelled culturally to do so.

Regarding the dichotomous relationship between *partnerships* and *support functions*, the short logical explanation is that a typical plant, with limited resources, struggles to support both a broad based internal Lean system and a broad based external Lean system. Simply put, plants have either vertically integrated or horizontally integrated their Lean systems. It was observed during statistical analysis that *partnerships* and *support functions* are indeed inversely correlated to one another at strong ($P < 0.01$) level of significance. This provides strong statistical evidence that with presumably limited resources a plant can't go both "deep" internally and "wide" externally with its Lean implementation. And, that the plants that favor going deep internally, by taking a holistic approach to implementing the Lean system throughout all facets of the operation, transcend to Green manufacturing.

Lean Results Discussion

It was not intended this way, but simply as a matter of coincidence, the best findings have been saved for last. The correlations between many Green variables, in all three categories (GMS, GWRT, and GR) and all four Lean results variables (i.e. Quality, Cost, Delivery, Customer satisfaction and profitability) are so strong, that it can be said without hesitation that Lean companies who embrace Green practices, have significantly better Lean performance results. In this case, synergy is realized when Green best practices significantly correlate to both Green and Lean results. This implies that the Green manufacturing system serves as a catalyst to the Lean system, yielding better Lean results than plants that do not have a Green manufacturing system in place.

It is important to emphasize that the Lean system was measured in this study by Shingo examiners with little thought to the environmental practices going on in the plant. This minimizes any risk of biasing the Lean Results scores, relative to Green management system and Green waste reducing techniques. These Green best practices were only identified from the survey that was administered well after the Lean scores were placed in the Shingo Prize database. Let's discuss in detail these remarkable findings of Green variables to Lean results. Again, this section is organized in the order of Lean results variables seen in the left hand side of table 15, with detail regarding correlations with respective Green variables within each section, specifically:

- IVA – Quality
- IVB – Cost
- IVC – Delivery
- V – Customer satisfaction and Profitability
- LR – Overall Lean results

Quality

The Lean results variable *Quality* correlates significantly and positively to the *status of the Environmental management system/ISO14001*. This Lean variable measures quality performance as measured by a group of Lean experts, with little eye toward environmental matters. Before discussing this correlation further, let's first define these variables from the Shingo Criteria and the Green survey.

IVA. Quality and quality improvement

The objective of the quality & quality improvement category is to insure that no human or machine errors ever get into customers' hands and that in-process defects are continually being reduced. The goal is zero defects. Both trend and level data should be presented and the basis/definition for all quality measurements should be reported.

Expected measurements:

- Rework as a percent of sales or production costs
- Customer rejects due to quality (ppm)
- Finished product first pass yield and percentage
- Unplanned scrap rate(s)

Supplemental data could include:

- Overall cost of quality as a percent of sales, total manufacturing cost or other appropriate baseline
- Process variation measures
- Warranty cost as a percent of sales
- Other appropriate measures

(Shingo, 2003)

- GMS1 (Status of GMS): Status of plants Green management system implementation.

In looking closely at the criteria for *Quality*, there is considerable reference to process yield, rework, scrap, process variation, warranty costs, customer rejects, total manufacturing costs. Obviously these are true indicators of process quality and are appropriate for this Lean variable. Yet, it is from this vantage point of the Lean system that one can begin to see the direct connection to the objectives of a Green system. The ideal Green process has perfect yield, with no scrap: All resources end up in the finished product with no solid or hazardous waste byproducts. Products have a long and useful life, with minimal customer rejects or warranty costs. Total cost of manufacturing is minimized as higher levels of resource efficiency are achieved.

It is a fundamental requirement of ISO14001 that the plant establish environmental goals and objectives that drive the organization to continually reduce environmental waste, and have a formal management review process to make sure the goals are realized. You can't achieve ISO14001 certification without it. The metrics and goals of the Environmental management system typically include the same criteria listed in the Shingo quality criteria. Thus, it is only logical that the evidence of a formal EMS, as measured in this study by the variable GMS1, correlates strongly to quality improvement.

As an alternative explanation, it is also reasonable to assume that the quality improvements have an indirect association with the environmental management system. That is to say, the results may be truly the function of a comprehensive Quality management system (ISO9000) that may have led to the implementation of ISO14001. Much has been written about the presence of a formal Quality Management System (ISO9000) and a formal Environmental Management System (ISO14001) (King, Lenox, 2001). It was, after all, the success of ISO9000 that led to the birth of ISO14000. They are very similar in structure and companies that are comfortable with ISO9000 would naturally be drawn to ISO14000 if they were interested in environmental improvement.

Cost

The Lean results variable *Cost* significantly and positively correlates to *status of the Environmental management system/ISO14001, Overall GMS score, Reduce, Returnable packaging, Creating markets, Waste segregation, Over all Green*

waste reducing techniques, Improved equipment selection, Total Green score.

To better understand these relationships, let's explore the complete definition of the variables from the Shingo Prize criteria and the Green survey:

B. Cost and productivity improvement

The purpose of the measured cost and productivity improvement category is to assess the improvement trend and level in cost and productivity. Both trend and level data should be presented and the basis/definition for all cost and productivity measurements should be reported.

Expected measurements:

- Total inventory turns separated as appropriate into raw, WIP and finished goods.
- Value added per payroll dollar (sales minus purchased goods and services divided by total payroll dollars)
- Manufacturing cycle time (start of product production to completion)

Supplemental data could include:

- Physical labor productivity (units/direct hour)
- Energy productivity
- Product cost reduction
- Percent machine uptime
- Changeover reductions
- Resource utilization (e.g., vehicles, plant and warehouse floor space, etc.)
- Transport and logistics effectiveness and cost
- Other appropriate measures

(Shingo, 2003)

- GMS1 – Status of environmental management system (ISO14001)
- GMS – Overall Green management system score
- GWRT3 – Substitution replacing a material which can cause environmental problems with another material which is not problematic
- GWRT10 – Returnable packaging: Using packaging and pallets which can be returned after they are finished being used
- GWRT12 – Creating markets: treating waste as an input to another product which can be made and sold at a profit
- GWRT13 – Waste Segregation: an intermediate action in which waste streams are separated out into their individual components before being recycled, reused or consumed internally
- GWRT – Overall Green Waste Reducing Techniques

- GR8 – Improved equipment selection
- GREEN – Overall Green score

This particular finding is perhaps the most powerful of the entire study. There can be little debate that one of the most important overall measures of Lean and manufacturing in general is total cost reduction. To make this point, each of the other Lean results measures (i.e. Quality, Delivery, Customer satisfaction, and Profitability) have cost reduction components built into their criteria, because the ultimate measure of any business in a capitalist society is financial. What is most striking is that not only does this variable correlate with several Green sub-variables, but that it correlates strongly with the main variables *Overall Green management system*, *Overall Green waste reducing techniques*, and *Overall Green score*. It can hardly be more evident that the Green system positively correlates to total cost reduction, as measured by an objective, non-environmentally biased panel of experts.

From the Shingo criteria, *Cost* is a broad based measure of operational costs generally associated with Lean manufacturing systems as well as traditional production cost accounting systems. Thus, Green variables that positively correlate with variable IVB can be said to positively correlate to manufacturing cost reduction in a very generally applicable fashion. To better understand the relationship between the Green best practices and cost reduction let's explore the Green variable correlations categorically as they relate to the Lean cost variable IVB to better understand the logic behind these relationships.

The *status of the Environmental management system/ISO14001 and the overall Green management system* variables both positively and significantly correlate to *Cost*. This is a strong indication the presence of an ISO14001 certified environmental management system, is closely associated with cost reduction in the manufacturing plant.

Substitution of hazardous raw materials, use of returnable packaging, waste segregation, and creating market for waste products, positively and significantly correlate to cost. All of these waste reducing techniques speak to material resource efficiency and avoiding the generation of environmental wastes. This is a clear indication that emphasizing total waste reduction drives total cost reduction.

Total cost reduction is the ultimate bottom line measure of a manufacturing operation and the one measure that is most highly regarded by the executives and shareholders who set policy and strategy for the manufacturing plant. Thus, it is of critical importance in making the case that Green is compatible with Lean to show a positive correlation to Lean cost reduction. The fact that the main Green variables *GMS*, *GWRT* and the overall measure of the Green system (*GREEN*) correlate strongly to *Cost*, puts to rest any argument that Green strategies are not cost effective. These findings indicate that the existence of a Green manufacturing system is an essential catalyst to the Lean system to realizing the greatest cost reduction. This result is a strong indicator that a focus on total waste reduction (Lean and Green) results in total cost reduction, and the

ultimate financial justification for integrating Lean and Green manufacturing systems.

Delivery

The Lean results *Delivery* positively and significantly correlates with the Green variable *Creating markets*. To better understand these relationships, let's explore the complete definition of the variables from the Shingo Prize criteria and the Green survey:

IVC: Delivery and service improvement

The purpose of the delivery and service improvement category is to identify whether customers are getting what they need in the time and quantity necessary. Both trend and level data should be presented and the basis/definition for all delivery and service measurements should be reported.

Expected measurements:

- Percent of line items shipped on-time (define on-time window) and/or percent of complete orders shipped on-time (define on-time window)
- Customer lead time (order entry to shipment)
- Premium freight as a percent of production costs

Supplemental data could include:

- Mis-shipments
- Warranty response and service
- Other appropriate measures

(Shingo, 2003)

- GWRT10: Creating a market for waste products: Treating waste as an input to another product which can be made and sold at a profit

This is a logical relationship, given that both are indicators of delivery and logistics of products and bi-products respectively. This may suggest that Lean companies with particularly strong delivery and logistics performance, are

inclined to utilize this capability to find creative alternatives to sending waste to landfills, and instead profit from delivering waste products to companies that can use their waste as process inputs.

It is reasonable to assume that if a company seeks markets for the waste products it would strive to deliver them efficiently. This could then spill over to the delivery and logistics capabilities of their main products, which results in improved performance as measured by the Shingo experts. The results from this section could indicate that this integrated approach to forward and reverse logistics is taking place at some of these plants.

Customer Satisfaction and Profitability

Lean results variable *Customer satisfaction and Profitability* positively and significantly correlates to Green waste reducing technique variables *Substitution, Prolong Use, Creating markets, Waste segregation*. To better understand these relationships, let's explore the complete definition of the variables from the Shingo Prize criteria and the Green survey:

V: Customer satisfaction and Profitability

This section is intended to evaluate the outcomes of quality, cost and delivery on customer satisfaction and business results. For each measurement presented, three (3) or more years of results should be documented.

Customer Satisfaction -

Evidence of customer satisfaction may be presented through any valid approach used by the company. Survey data should describe sample size, survey format, frequency and efforts to avoid bias. Measures reported must be clearly defined and could include, but are not limited to:

- Market share
- Reorder rate

- Customer survey results
- Customer awards
- Customer audits
- Field performance data
- Other appropriate measures

Profitability -

Measures of level and trend should be clearly defined and should document the unit's overall relevant business financial attainment.

Expected measurements:

- Operating income on sales ratio
- Operating income on manufacturing assets ratio

Supplemental data could include:

- Reductions in fixed and/or variable costs
- Cash flow
- Product line margins
- Other appropriate measures

(Shingo, 2003)

- GWRT4: Substitution: replacing a material which can cause environmental problems with another material which is not problematic
- GWRT9: Prolong Use: reducing environmental problems by increasing the overall life of the product (e.g. engines which last longer before having to be replaced or rebuilt)
- GWRT12: Creating a market for waste products: Treating waste as an input to another product which can be made and sold at a profit
- GWRT13: Waste Segregation: An intermediate action in which waste streams are separated out into their individual components before being recycled, reused or consumed internally

Let's explore these correlations first from the perspective of *Customer satisfaction* and then from the perspective of profitability. The Shingo criteria of customer satisfaction appears sufficient for measuring true satisfaction of the end user of the manufacturing plant's products. In looking at the GWRT definitions, there seems to be at least two logical relationships to customer satisfaction. First, it would seem desirable to customers to know that their products were produced in a least hazardous way through *Substituting* hazardous materials with

more benign materials. Secondly and certainly more logically, *Prolonging the use* of products would naturally translate to customer satisfaction, as customers would get significantly more use out their product and thus greater value for their purchase.

From the perspective of *Profitability*, a logical argument can be made for all four GWRT variables. First, *Substitution* of hazardous materials is a practice identified in Waste Minimization/Pollution prevention literature, which can reduce waste management costs, processing costs, and even raw material purchasing costs (EPA, 2001). Secondly, products with *Prolonged use*, can command a market price premium over brands that do not last as long. This is commonly seen in the automotive industry. Prolonged use, also means less warranty repair costs. Thirdly, *Creating a market for waste products* means that instead of paying someone to take your waste, you are being paid for your waste. Finally, *waste segregation*, means steps are being taken to get the most return on saleable waste products, and reduce waste management costs overall. Each of these examples either lower operating costs and/or allow for a higher price in the market place, which together translate into enhanced profitability.

The *overall Lean results* correlated positively and significantly with the Status of the Environmental management system/ISO14001, *Substitution, Creating markets, Waste segregation, and Total Green waste reducing techniques*. Since each of the Green sub-variables listed have been discussed as to their correlation with specific Lean results sub-variables, there is little to offer at this

point other than to state that it is further proof, that these particular Green sub-variables share a very positive relationship with the overall set of Lean results. For completeness, the definitions of the Green variables that positively and significantly correlate to *Overall Lean results* are as follows:

- GMS1 – Status of environmental management system (ISO14001)
- GMS – Overall Green management system score
- GWRT3 – Substitution replacing a material which can cause environmental problems with another material which is not problematic
- GWRT10 – Returnable packaging: Using packaging and pallets which can be returned after they are finished being used
- GWRT12 – Creating markets: treating waste as an input to another product which can be made and sold at a profit
- GWRT13 – Waste Segregation: an intermediate action in which waste streams are separated out into their individual components before being recycled, reused or consumed internally
- GWRT – Overall Green Waste Reducing Techniques

What is worth discussing is the fact that *Overall Lean results* correlates positively and significantly with *Overall Green waste reducing techniques*. This is a remarkable finding in terms of its implications to the future integration of these manufacturing systems. What this finding implies, is that of the population of Lean companies in this study who have opted to complement their Lean system implementation with a broad set of Green waste reducing techniques are realizing significantly better results in both Green results and Lean results than the other Lean plants in the study. This finding not only suggests that Lean and Green systems can co-exist, but that there is evidence of *synergy*, by the virtue of the fact that Green waste reducing techniques simultaneously improve Green and Lean results. And, the evidence from hypothesis I (p.6), whereby known

Lean manufacturers exhibit disproportionately higher Green results than the general population of manufacturing plants, indicating that the Lean system is having a positive effect on Green results.

It's important to note that the Lean results were measured completely separately from the Green waste reducing techniques by a set of Lean experts with no particular eye towards environmental behavior. It is also important to state another view of this correlation, given that causality of Green waste reducing techniques cannot be proven, just logically suggested. The complementary view, given this correlation, is that successful Lean plants, as seen by their strong Lean results, tend to seek out new forms of waste to eliminate, which includes the use of Green waste reducing techniques. That is to say, that rather than assume the application of Green waste reducing techniques contributed to Lean results, the success of the Lean program, as seen by the strong Lean results, served as a catalyst to the implementation of Green waste reducing techniques. This would be another example of Lean *transcendence* to Green manufacturing.

Regression Discussion

In order to fully explore this complementary relationship between Green waste reducing techniques (*GWRT*) and the Lean system, regression analysis was performed combining *GWRT* with the main Lean variables *Lean management system* and combining *GWRT* and *Lean waste reducing techniques (LWRT)* as sets of independent variables and *Lean results (LR)* as the dependent variable.

The results of the regression analysis are in tables 17 and 18 of the results chapter.

In both cases the overall model was significant and *GWRT* was significant along with the Lean counter parts. These results suggest a complementary nature of *Green waste reducing techniques* when integrated with *Lean management systems* and *Lean waste reducing techniques* in improving *Lean results*. This is further proof that integrating Lean and Green best practices can have very powerful and positive results. The overall findings imply there are opportunities to integrate Lean and Green into a single “Zero Waste Manufacturing” system that can remove redundancy and improve the efficiency of holistic waste reduction.

Chapter Summary

This chapter discussed the results presented in Chapter Five in order to explain the meaning of the statistics and the implications of these findings to the general manufacturing population. This discussion will be summarized into specific conclusions in the next chapter. Chapter seven will also describe industrial application of these conclusions, and opportunities for further research.

Chapter Seven

Conclusions and Recommendations

Review of Research

Phenomena such as global warming and rapid population growth make us realize the fragile and finite nature of our planet earth. As we continue to exceed the earth's capacities to provide natural resources and process wastes, we actually reduce these capacities, triggering a downward spiral toward ecological collapse. Philosophical frameworks, such as Sustainable Development and Industrial Ecology, have emerged to help us visualize a future where we enjoy the benefits of industrialization without environmental devastation. As the whole world seeks to industrialize, and manufacturing is pushed to developing nations, waste-free manufacturing systems are ever more critical to the future of humanity. Designing elegant industrial systems that mirror the earth's waste-free processes presents the ultimate challenge for industrial engineers in the twenty-first century, and is the key to our sustainable future.

This study took one step toward industrial sustainability by exploring the relationship between the two leading manufacturing systems that target waste: Lean manufacturing and Green manufacturing. While Green manufacturing more directly addresses the global environmental challenge, Lean manufacturing has emerged as the most economically efficient system for producing quality

products, on time, tailored to customer needs. Although Green manufacturing has proven to lower operating costs, limitations of economic equations that do not properly account for natural capital, mute the true benefits of Green manufacturing systems. Thus, there has been great interest in marrying Lean and Green systems, so as to simultaneously realize economic and environmental sustainability.

The literature review, detailed in chapter two of this dissertation, found studies that explored the Lean and Green relationship in a variety of ways. Dr. Sandra Rothenberg studied the correlation between the level of automotive manufacturers' Leanness and environmental metrics (e.g. waste emissions, water and energy usage, etc.). Dr. Richard Florida, discovered that larger more technically advanced companies more readily embraced the Green manufacturing practices, rather than smaller less advanced companies that chose traditional waste management practices.

Ross and associates (and the EPA) case study of Boeing, found that Lean creates a culture highly conducive to environmental waste minimization and pollution prevention. They found that Lean initiatives have environmentally beneficial by-products, such as less space and energy needs per unit of output, and reduction in material scrap. They also identified that environmental agencies have a window of opportunity to integrate environmental practices into Lean systems, to leverage the rapid expansion of Lean. The EPA indicates it is very interested in research that helps "build a bridge" between Lean and Green

systems, so that the rapid deployment of Lean systems serves as a catalyst for Green manufacturing and resulting environmental improvements.

Simultaneous to the research on the relationship between Lean and Green systems, was research regarding the major components within Lean and Green systems. Researchers at the Shingo Prize team at Utah State University (Shingo, 2003), Jeffery Liker (2004), and Society of Automotive Engineers (SAE, 1999), were expanding the definition of Lean from a set of process improvement tools to an entire system of operation. They defined Lean in dimensions of the management system that creates the Lean culture, waste reducing techniques that are proven to eliminate waste in the process, and measurable business results that companies realize by following the Lean business model.

In parallel to Lean system research, Green manufacturing researchers such as Melnyk et.al. (2003), Russo (2001), and the EPA (2003) were looking into the relationships between the international ISO14001 Environmental Management System (EMS) and environmental waste minimization and pollution prevention techniques. They found that the existence of a formal environmental management system was essential in creating the culture that drove environmental improvement activity. Both Lean and Green research efforts in recent years have made it clear that a systemic approach, that combines a formal management system with aggressive implementation of the waste reducing techniques, are critical to driving sustained results.

Synthesizing all of this literature led me to create a series of Venn diagrams to visually depict the evolution of Lean and Green manufacturing systems, specifically in relationship to each other. The Venn diagrams depict four evolutionary phases, and are copied from chapter three for convenience below.

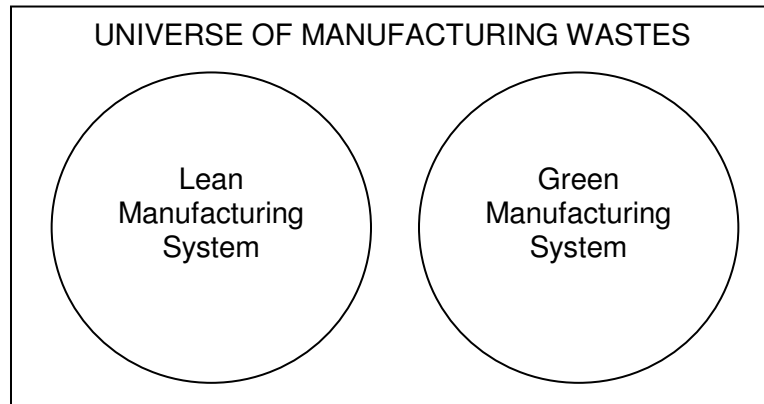
The first phase “parallelism” describes the traditional and still commonly practiced view, that these are two separate waste reducing systems that may co-exist within a single manufacturing operation, but share little in terms of resources, best practices, and results. In this evolutionary phase, there is still skepticism that these systems are complementary, and that trade-offs will have to be made between environmental and business improvement.

The second diagram “convergence” is the view described in the Lean and Green studies referenced in the literature review. There is a general feeling these systems are complementary, and elimination of waste in any form is good for business. Best practices are being shared between disciplines. Lean companies may incorporate some Green practices within their Lean systems, but are not committing the implementation of a broader Green system, and vice versa.

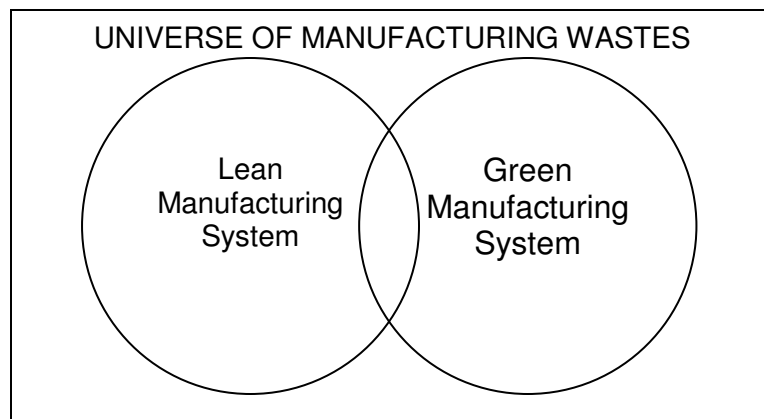
The third view “transcendence” helped me visualize the next logical phase of this evolution, which really had not been explored. In this view the expansion of one of these systems, and the resulting waste reducing culture created, triggers transcendence to the other system. Manufacturing plants that deeply commit to Lean systems develop such a strong culture of waste reduction, they commit to a

Green manufacturing system as a logical next step in their waste elimination quest. It can also be said for companies who first commit themselves to Green manufacturing, that they eventually seek the most efficient model of manufacturing (Lean) as a logical continuation of their efforts to reduce environmental impacts.

My mind then wondered to a utopian phase of the future, “Synergy”, whereby the distinction between these two systems ends and a single and holistic Zero Waste Manufacturing system emerges. In this culture employees are encouraged to target all forms of waste, and have in their arsenal the best practices from both disciplines. This zero waste approach eliminates the redundancy and conflicting practices between Lean and Green systems, thus continually improving the efficiency of the waste elimination process/system itself. Higher levels of effectiveness are evident as waste elimination efforts simultaneously improve both Lean and Green result metrics. The Earth itself serves as the only respectable process benchmark for Zero Waste Managers. Sustainability is realized, as manufacturers provide the products we need, without the traditional sacrifices to environmental quality.

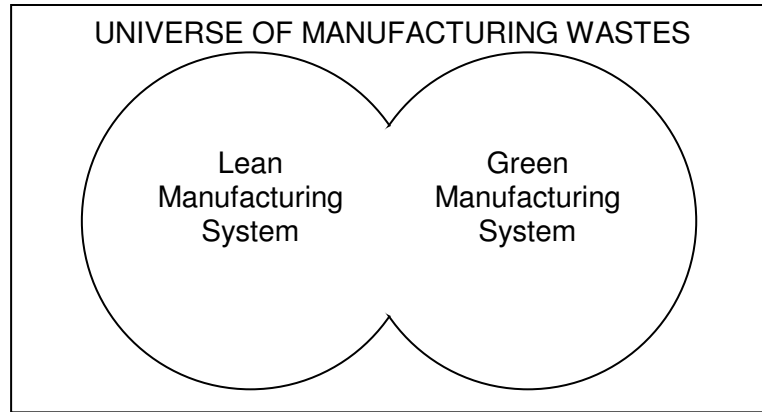


PARALLELISM: The traditional view whereby Lean and Green best practices are considered distinct sets of solutions targeting different forms of wastes. Some consider these efforts as conflicting. Best practices are administered by separate organizations operating in “parallel universes” of waste reduction.

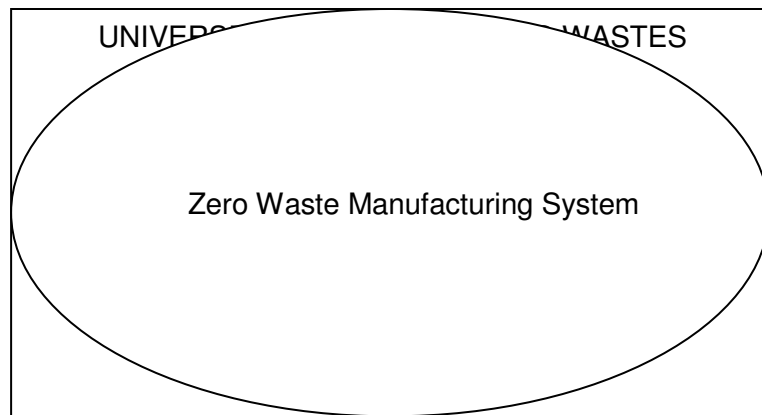


CONVERGENCE: The modern view, whereby Lean and Green best practices are considered complementary. Best practices from one discipline are successfully applied to reduce the other discipline’s wastes. Continuous improvement teams are starting to look at solutions that are both Lean and Green.

Figure 15. Evolution of Lean and Green Manufacturing Systems



TRANSCENDENCE: *The view suggested in this study.* Companies that are actively implementing Lean or Green manufacturing systems not only fully explore the common solutions (intersection of Lean and Green best practices) but also start down the path of implementing the other manufacturing system. Lean and Green manufacturing systems serve as a dual-catalyst to each other. Employees throughout the company implement a broad set of best practice targeting the full spectrum of wastes associated with both Lean and Green manufacturing systems.



SYNERGY: The Future, whereby distinctions between Lean and Green systems ends, and *Zero Waste Manufacturing* is the new holistic manufacturing system. Elimination of all forms of waste is the new corporate mantra. Synergy is realized as aggressive efforts to reduce waste results in continuous efficiency, quality, service and environmental improvements. New best practices evolve as new forms of waste are identified, beyond the present boundaries of Lean or Green wastes. *The Earth itself serves as the model for manufacturing perfection and the never-ending pursuit of zero waste manufacturers.*

Figure 15. (Continued)

The Venn diagrams were helpful in defining a research gap and articulating the research opportunity that formed the basis for this study. Was there evidence of transcendence to Green manufacturing by Lean manufacturers? Specifically, was there a linear correlation between a company's level of Lean system implementation and its level of Green system implementation, measured from the perspective of the management system, waste reducing techniques, and results? This led to the search for objective and credible instruments for both Lean and Green manufacturing systems, which measured all three major system components (i.e. management system, waste reducing techniques, and results).

After thorough research, it became evident that the most complete and objective measure of the Lean system was the Shingo Prize for Excellence in Manufacturing, administered by Utah State University's School of Business. The Shingo prize has been objectively measuring manufacturing plants with a panel of Lean experts since 1988. The Shingo prize criteria is now officially the basis for the new national lean certification, that was created in collaboration with the Shingo team, Association for Manufacturing Excellence (AME), and Society of Manufacturing Engineers (SME), three leading associations of manufacturing excellence. (SME, 2006)

The Executive Director of the Shingo Prize, Dr. Ross Robson, had recently become aware of the potential relationship of Lean and Green systems, through conversations with Ross & Associates, who were studying the Green aspects of Boeing's Lean efforts, for the EPA. Dr. Robson, was eager to support further

research on this subject, and granted me confidential access to the Shingo Prize database that housed objective measures of leading Lean manufacturers best practices. He also provided support of his staff to administer an on-line survey to measure the Green practices of these leading Lean manufacturers.

I was fortunate to locate a recent survey on Green manufacturing best practices (Melnyk et. al. 2003) that categorically mirrored the Shingo scoring system, yet was very user friendly. The survey struck a nice balance between brevity and breadth of the Green system by covering the management system, waste reducing techniques, and results, in an efficient twenty-six questions survey. The Melnyk survey was also generic enough to be applicable to any manufacturing sector. All too often, environmental research instruments are very industry specific, down to the use of chemical composition (i.e. TRI database, EPA), making it very difficult to compare environmental performance across manufacturing sectors.

The manufacturing plants that were deemed eligible for the study had attained high enough levels of Leanness to earn a site visit by the Shingo examiners. These companies can all be considered Lean as confirmed by the panel of experts, but vary in degrees of Leanness based on their Shingo Prize scoring system scores. The one thousand point Shingo Prize scoring system scale, which covered all critical aspects of the Lean management system, waste reducing techniques and results, provided the ideal set of independent variables for the study. The population of “Shingo” manufacturing plants was controlled by

the year (2000 and later) of examination to assure the scores were reasonably accurate depictions of their current states. The year of examination was also used as a control variable in the study to account for changes from when the plant was examined and when it completed the Green survey.

The Green system survey, borrowed from the Melnyk study was administered to the one hundred and ten eligible Shingo plants, via an invitation email from Dr. Ross Robson, the Executive Director of the Shingo Prize. Chris Paulus of USF, created the on-line survey and database to capture Green survey results. Each plant was provided a privacy code to enter in the survey as a confidential way to key the survey results with the Shingo prize scoring system database. It took several months and several rounds of reminder emails and phone calls to yield the forty-seven usable responses that comprised the data set for the study. The methodology is detailed on Chapter four of this dissertation.

SAS statistical software was utilized to determine if statistically significant correlations existed between Lean and Green system components. This analysis was performed at the high level variables associated with the main hypotheses and at the sub-variable level for the individual best practices and metrics that make up each high level variable for both Lean and Green systems. Regression analysis was also performed to better understand multi-variant relationships. Statistical analysis and full discussion of the results are detailed in Chapters five and six of this dissertation, respectively, and the conclusions are summarized below.

Conclusions

1) Known Lean plants are significantly Greener than the general manufacturing population. The survey statistics of the Shingo plants in this study were compared to the survey statistics from the original Melnyk study, which surveyed the general manufacturing population. The results indicate that the Shingo plants were significantly Greener in all but one of the twenty-six Green manufacturing system measures. These findings are strong evidence of *transcendence* to Green manufacturing by leading Lean manufacturers.

For all ten Green results variables, the Shingo plants were significantly higher at the $P < 0.0001$ level, than the Melnyk population. This is disproportionate to comparison of statistics of Green waste reducing techniques between Shingo and Melnyk plants. This suggests that having a Lean system infrastructure serves as a catalyst to the successful implementation of corresponding results of Green best practices. The evidence that plants with Lean systems yield higher Green results supports the philosophical notion of Lean and Green synergy.

2) Mexican Lean plants are Greener than United States Lean plants. Within the set of Shingo plants utilized in this study, Mexican plants exhibit higher levels of Green waste reducing techniques and corresponding results than plants located in the US. The particular waste reducing techniques that the Mexican plants more readily adopt focus on material conservation, perhaps at the expense of additional labor. Mexican plants also seem more inclined to develop industrial partnerships to resolve environmental issues. As a result, Mexican Lean plants

experience significantly higher levels of performance from their environmental efforts in the areas including quality, sales, market position and reputation.

3) There is a critical need for strategic integration of Lean and Green manufacturing systems at the management systems level. No significant correlations were found between Lean and Green management system variables. Additionally, there were several negative correlations between Green management system and Lean waste reducing techniques, and Lean management system (and strategy), and Green waste reducing techniques and results. These findings suggest that there is very little integration of Lean and Green manufacturing systems at the management system or strategic level.

It has been proven statistically for both Lean and Green systems that the management system is critical to create the culture/environment that drives the implementation and sustaining of waste reducing techniques. It was also found that waste reducing techniques strongly correlate to results. Thus, without an integrated Lean and Green management system, it is unlikely that integration of Lean and Green waste reducing techniques will occur, and synergistic results will be minimal. But, if integration were to occur at the strategic level, it would stimulate holistic approaches to waste reduction and corresponding synergies at the plant level.

Integration of management systems may be the most important and attainable goal of post-doctoral research for the following reasons. The management system articulates management commitment in the form of policy, measurable

objectives, resource allocation, and a formal review process. It is the management system that establishes formal commitment and leadership of the plant's executives and senior managers. Without it, there is constant infighting as to what waste reducing techniques should be implemented, and they are rarely sustained. With a management system in place, there is clear and active leadership that prioritizes and synchronizes waste reduction across the entire plant.

In manufacturing plants with weak or no management systems, process improvements are localized to the functional area where the interested manager can affect change. True systemic waste reduction requires total cross-functional collaboration and senior management to remove barriers and break the ties when functional managers are at odds. It takes a holistic and strategic view that weighs the short term needs to the broader, even global, challenges of the business and the environment

4) Green manufacturing drives Lean results, particularly improved cost performance. Shingo plants that have succeeded in implementing Green management systems and Green waste reducing techniques, show significantly higher Lean results than Shingo plants less environmentally inclined. This is an indication of *synergy* in that Green manufacturing practices simultaneously improve Green and Lean results when implemented in a Lean environment. The fact that Lean results were measured objectively by a team of Lean experts, with

little regard to environmental practices, makes this particular conclusion very strong.

Green variables from all three categories (management system, waste reducing techniques, and results) positively and significantly correlated to all categories of Lean results (Quality, Cost, Delivery, Customer satisfaction and profitability).

Most striking, is how strongly the Green variables (including *GREEN*-overall green survey score) correlated to the Lean variable *Cost*, perhaps the most important measure of Lean, as viewed by stakeholders. This is a very powerful conclusion that financially justifies further research into the integration of these systems into a single Zero Waste Manufacturing strategy.

5) Plants that choose vertical versus horizontal integration of their Lean systems transcend to Green manufacturing. It was found that transcendence to Green manufacturing was significantly stronger in Lean plants that chose to vertically integrate their Lean systems versus plants that chose to horizontally integrate their Lean systems. The Lean variable *Partnerships* measures horizontal integration of the Lean system throughout the extended enterprise of suppliers and customers. The Lean variable *Support functions* measures vertical integration of the Lean system within the internal functions of the manufacturing plant. Respectively, *Partnerships* and *Support Functions* negatively and positively correlate to a very similar set of Green variables in all three categories (management system, waste reducing techniques, and results). The conclusion drawn from these statistics is that manufacturing plants that implement Lean

holistically throughout all plant functions *transcend* to holistic approach to waste elimination itself, and embrace Green manufacturing practices.

Additionally, *Partnerships* negatively correlates to *Support Functions* indicating a plant may have to choose, based on resource constraints, to deploy Lean horizontally or vertically. There are two sayings in the Lean community that speak to vertical integration preceding horizontal integration of the Lean system. One is “Clean up you own house, before you ask others to clean up theirs”. The second is when implementing Lean “go an inch wide and a mile deep” (Liker, 2004). Both of these sayings are meant to emphasize the critical importance of institutionalizing the Lean system to the point where it takes hold culturally before moving on the next process of business partner. Else, things will quickly resume to the old way and the Lean system cannot sustain itself.

The goal of Lean system implementation is to create a “learning organization” empowered to continuously eliminate waste. This takes relentless reinforcement. It is easy to imagine how employees in a work environment that constantly reinforces the importance of waste elimination develop a keen eye for any form of waste, including environmental waste. It appears from this study, the plants that were strongest in vertical integration also were strongest in Green waste reducing techniques. This illustrates how building a learning organization of empowered waste eliminators is an essential point of transcendence to Green manufacturing.

6) Focus on synergistic Lean and Green practices to optimize the finite amount of human resources working on waste reduction. By virtue of the fact that no company has unlimited human resources to work on improvement projects, priority must be given to projects that eliminate “the most waste for the buck”. This means prioritizing solutions that maximize Lean and Green synergies and eliminate several forms of Lean and Green wastes simultaneously. There is evidence of best practices negatively correlating with the other systems’ best practices, indicating points of conflict between systems. On the other hand there are indications of very complementary practices that realize benefits in both disciplines. Companies interested in improving performance results associated with both Lean and Green systems must focus on the complementary practices and find alternatives to conflicting ones.

7) It is time to create a Zero Waste Manufacturing system model. This study indicates that there are substantial research opportunities to create a holistic Lean and Green manufacturing model that maximizes complementary Lean and Green practices and minimizes conflicting practices, to improve the efficiency and effectiveness of total waste reduction efforts. The Lean manufacturing system has matured over the past sixty years and is now reaching a point of total consensus and standardization. Green manufacturing is newer than Lean and has yet to realize consensus on a single system model, except for the management system component (ISO14001). Given the maturity and success of Lean, it makes sense to use Lean as the core of the Zero Waste Manufacturing system model.

The fact that Green manufacturing practices serve as a catalyst to Lean results indicates the great potential for integration. In short, Lean manufacturing can provide the structure and broad acceptance Green manufacturing has been missing. Green manufacturing will enhance the performance of Lean efforts and address ever more pressing environmental issues companies and society face. Uniting Lean and Green into a single well-defined Zero Waste Manufacturing system, will realize efficiencies and synergies well beyond what was found in this study. Besides, now that Lean manufacturing is reaching such a state of maturity and general acceptance, leading edge companies are probably looking for ways to differentiate their Lean programs from competitors and are facing growing public pressure to address environmental issues.

8) There may be Zero Waste Manufacturers in our midst. Strong evidence of transcendence and synergy between Lean and Green manufacturing systems makes me wonder whether some of the companies in this study are already practicing what's been dubbed "Zero Waste Manufacturing". Granted, it was not proven that all manufacturers get Greener as they get Leaner, but there is evidence that several of the known Shingo plants are strongly committed to Green manufacturing. What is not known is whether they have attempted to integrate these strategies or do they simply co-exist within the same plant. I very much hope I will have the opportunity to study the population of the Shingo plants exhibiting the highest levels of Green manufacturing practices and understand where integration exists. I have also spoken to Dr. Jeffery Liker

(Toyota Way) about understanding more about what Toyota is doing to integrate Green into their Lean systems.

Implications for Practitioners

Until a Zero Waste Manufacturing (ZWM) model emerges, practitioners should begin to seek ways to integrate Lean and Green manufacturing systems within their own plants. This study showed several areas where Lean and Green manufacturing systems are complementary and even synergistic. Yet it also indicated conflicting practices remain. Practitioners should evaluate their current Lean and Green practices and emphasize the complementary and synergistic practices while seeking alternatives to conflicting practices that interfere with the objectives of the other system.

Practitioners at the strategic level should focus on integrating Lean and Green management systems. Manufacturing executives should take a close look at their policy statements, metrics/goals, resource allocation, training, management review processes, etc., and begin to integrate them. Integrating Lean and Green management systems will encourage cross-functional collaboration toward minimizing a holistic set of wastes. Lack of integration will cause confusion by employees, who struggle to align their tactical priorities with the company's dual system objectives. Care must be taken in establishing metrics and waste reduction targets that, while broad-based, do not overwhelm and paralyze practitioners. Highest priority and resource allocation should be given to

synergistic projects that simultaneously improve several Lean and Green waste metrics.

Beyond improving the overall efficiency of waste reduction efforts and reducing confusion amongst employees, there is an added benefit to employee morale when integrating Green into the Lean strategy. Case studies of Green companies indicate how employees are energized working for socially conscious companies trying to make the world safer for them and their children.

Environmental and socially conscious behavior on the part of executives creates a trusting environment, which has proven vital to the Lean system. (Smith, 2005) (Hawkins, 1999)

Companies serious about Lean make social pacts with employees to secure their employment. Employees willingly provide creative solutions to eliminate waste without fear that efficiency improvements may cost them their jobs (Liker, 2004). Lean companies know that, as the company improves its quality and efficiency through total employee involvement they will grow their market share and will need all of their employees to meet the future the market demand. By adding environmental commitment to management trust, Lean companies can create an ideal work environment that attracts the most creative and talented employees, fueling even greater business success.

Perhaps of greatest concern to the executive is the impression on the external stakeholder of the business. No doubt, the operational success of an integrated “Zero Waste Manufacturing” strategy will satisfy customers and shareholders

alike. But, there is also the aspect of corporate image. It seems in the past few years, global warming has become front and center in the minds of consumers, insurers, and even shareholders. It is now true that environmental considerations are required to sell products in the European Union (ROHS, 2006). Large corporations are lining up to proclaim their commitments to reducing Green house gases. Insurance companies are very nervous about the costs of global warming triggered natural disasters and this is spilling into risk assessment. And, stock traders avoid risky businesses like the plague. It is no surprise that global corporations are jumping onto the Green bandwagon. As if these factors weren't stimulus enough for executives to formally integrate Green into their Lean management systems, take a look at "this just in" from California.

8/31/06 SACRAMENTO (AP) — California would become the first state to impose a cap on all greenhouse gas emissions, including those from industrial plants, under a landmark deal reached Wednesday by Gov. Arnold Schwarzenegger and legislative Democrats. The agreement marks a clear break with the Bush administration and puts California on a path to reducing its emissions of carbon dioxide and other greenhouse gases by an estimated 25% by 2020. "The success of our system will be an example for other states and nations to follow as the fight against climate change continues," Schwarzenegger said in a statement. The bill would require the state's major industries — such as utility plants, oil and gas refineries, and cement kilns — to reduce their emissions of the pollutants widely believed to contribute to global warming. A key mechanism driving the reductions would be a market program allowing businesses to buy, sell and trade emission credits with other companies. The bill was praised by environmentalists as a step toward fighting global climate change but criticized by some business leaders, who say it would increase their costs and force them to scale back their California operations. "Adopting costly and unattainable regulations will drive businesses and jobs out of California into other states and even into other countries with no commitment to improve air quality," said Assembly Republican leader George Plescia, a LaJolla Republican.

Notice the argument about the negative effect this can have on industry. Now we have an imperative from the largest and most technically advanced industrial state in the US to find approaches to reduce environmental impact that do not

adversely affect traditional industrial efficiency. Interestingly enough, due to the market based approach chosen by California and the EU, companies that get a head start on reducing Greenhouse emissions can sell their credits to companies lagging behind. This means that Green is now a commodity. Manufacturing executives now have great incentive to integrate Lean and Green into a single Zero Waste Manufacturing (ZWM) system.

Practitioners working at the tactical or process level should seek vertical integration of the Lean system to include Green waste reducing techniques. Going “an inch wide and a mile deep” is good advice for both Lean and Green system implementation. Solutions like Kan ban systems satisfy the need to create “pull systems” critical to the Lean system and satisfy a returnable packaging requirement for Green systems.

Another example that comes to mind is to include environmental wastes into the popular Lean technique known as “Value stream mapping” (VSM). VSM is used to look at a plant at a high-level (A single sheet of paper) and identify Lean wastes. The first step is to create a current state identifying various forms of Lean wastes with a timeline on the bottom capturing value added time versus total lead-time. This is a tool to show at a high level the opportunities for waste elimination and to target areas based on the greatest waste reduction potential.

Imagine if overlaid on this value stream map were environmental waste wastes, such as energy loss, product scrap and hazardous and greenhouse gas emissions. This would allow the prioritization of projects from a total waste

minimization perspective. This is an excellent opportunity for integration of Lean and Green systems that could be implemented by practitioners rather easily.

Implications for Academics

Lean researchers should seek robust measures of the Lean system and not watered down versions. I was very fortunate in this study to have access to the most robust and objective measure of Leanness, the Shingo Prize Model database. I believe this made for solid research. Recently, the Shingo criteria have now become the national gold standard for the Lean body of knowledge, to which Lean professionals can receive certification. This will serve to standardize Lean systems to the Shingo model, making research based on this model generally applicable.

While it may seem unorthodox, I found the hybrid approach of using objective data for the Lean variables and a survey instrument for the Green variables afforded a strong data set. Previous studies had limited measures of Leanness, some missing the boat completely (i.e. King, Lenox's choice to use ISO9000 as their measure for Lean). As time goes on, the Shingo data set only gets larger and there will no doubt be better ways to entice more respondents to similar research in the future. In so doing, future Lean researchers can have a very strong and objective measure of Lean without sacrifices to sample size.

I do feel that this study's focus on operational practices rather than results is an important implication for future researchers. The management system and

waste reducing techniques identified in this study are generally applicable to most discrete manufacturers. This opens the door for more detailed comparison of a broader set of Green practices and their effect on Lean practices and on Lean and Green results. This could lead to a common set of Green best practices that make for a generally applicable model for a Green manufacturing system. Lean has had over fifty years to settle into a generally applicable system model. Green is still in its relative infancy, and needs more time and research to reach the state of the Lean system.

It is my sincere belief that any future research efforts to advance the Green model must have an eye toward Lean. It is hard to imagine any discrete manufacturer being interested in a Green system that does not complement a Lean system. I dare suggest that perhaps defining an independent Green system model at all may be a futile effort. Instead, a Zero Waste Manufacturing system model that leverages the complete Lean manufacturing system for its core and integrates complementary and synergistic Green practices will gain broad acceptance in industry.

Limitations of Research Study

The sample size of forty-seven companies seems small to make such bold claims in this study. Comfort can be taken in the validation process utilized, but there is always greater security in numbers. With every passing year, more companies apply for the Shingo prize, and now that it is the basis for the national Lean certification, the sample size for future research is growing. Standardization of

the Lean model will be very helpful in increasing sample size for future research on this subject.

The survey instrument itself was a limiting factor. To assure high response rates, surveys must be short in nature. This Green survey instrument was limited, particularly in the area of waste reducing techniques and result areas.

Noticeably missing from both categories were references to Green house gas emissions and energy, which in the past few years have become a very important issue and should be included in any future Green study. Also, had time and resources not been a factor, the use of objective measures as in EPA emissions data would have made for a stronger study. Work will have to be done to normalize emissions data by industry sector for fair comparison.

Also, surveys do not convey the details of what is really going behind the scenes that led to the results seen in the survey data. Having worked in manufacturing plants for twenty years, I know there is no substitute for visiting a plant and observing the process and talking to people throughout the organization. This is why the Shingo examiners conduct thorough site visits. Had time permitted to conduct case studies of each respondent, it would have yielded much richer understanding of where integration and conflict were occurring between Lean and Green manufacturing systems components. I sincerely hope I will be able to conduct such studies as a post-doctoral research effort.

Opportunities for Future Research

While this study identified that Lean and Green systems exhibit synergies and have great potential for integration, work must now begin to better understand integration points. The first step is to create a single Zero Waste Management model. The management system is the driving force for any manufacturing system and actually the most attainable point of integration. The management system component is the most generally applicable aspect of the broader manufacturing system, across manufacturing and other industrial sectors.

An academic exercise is required to compare and contrast the specific elements of generally accepted Lean and Green management system models. For example, now that the Shingo Lean management system model is the national standard, it can be merged with the ISO14001 international Environmental Management System standard, to create a single Zero Waste Management (ZWM) system standard. The ZWM model must satisfy the requirements of both Lean and Green management system standards while maximizing synergies between these systems.

The second opportunity is to integrate complementary Lean waste reducing techniques and Green waste reducing techniques into a single robust set of “Zero Waste Techniques” (ZWTs). To achieve this objective, an academic exercise that identifies obvious synergistic techniques (i.e. kan ban, value stream mapping) can be combined with field research. Case studies should be conducted for the plants in this study to understand how they are integrating their

Lean and Green efforts. Companies outside this study known for their strong Lean and Green performance (i.e. Toyota) should also be included in these studies. From these case studies a holistic set of ZWTs can emerge that can serve to build the ZWM model.

This leads to the obvious need to create a single set of “ZWM wastes” that an integrated ZWM strategy seeks to eliminate and corresponding result metrics. The set of Lean wastes has been agreed upon for many years (Defects, Over-production, Transport, Waiting, Inventory, Motion and excess-Processing (D.O.T.W.I.M.P.)), which has led to the standardization of waste reducing techniques, and a supportive management system.

For ZWM to share the same success as Lean, it too will need great specificity at this level. The set of Green wastes will need to be applicable and relevant to any manufacturer, or industrial organization, as are the Lean wastes. This will take further research to identify a short list of Green wastes, that when merged with the Lean wastes, creates the dozen or so ZWM wastes. Once this is complete, it will simplify the aforementioned process of identifying a holistic set of ZWTs that most efficiently reduces these wastes.

Very related to identifying a common set of wastes is to create a common set of performance metrics. To clarify, the wastes are generally the physical inefficiencies in the plant that once reduced reflect in a higher level metric. Examples of this in the Lean world are metrics like quality, cost, delivery and cycle-time. Cycle time is known as the driving metric for Lean as it measures

how well product flows through the plant. It is said that a plant with perfect flow must be waste free from a Lean perspective.

A similar set of Green metrics must be derived to monitor, or drive, Green waste reduction efforts and integrated with the generally accepted Lean metric set. As seen in this study, there are already several common result metrics between Lean and Green systems (Cost, quality, etc.) Clearly, generally applicable metrics of environmental impact (e.g. Green house and hazardous emissions) would need to be added to this set. All of this research should culminate in a series of articles, books, courses, templates and other tools to promote Zero Waste Manufacturing.

In order to fulfill the philosophical objectives of Sustainable Development and Industrial Ecology, practical tools and instruction are required to show people the way. Industrial engineering is an ideal discipline to promote ZWM research and curriculum development, as it addresses some of the most pressing issues affecting industry today. All of the components of ZWM are core to the industrial engineering discipline. Fervent interest in Lean throughout industry, growing concern about Green house gases (i.e. California legislation), and the EPA's desire to "build a bridge" between Lean and Green, point to great potential for funded research for industrial engineers on this subject.

Summary

Perhaps the greatest challenge and opportunity for industrial engineers in the twenty-first century is to devise industrial systems harmonious with earth's natural systems. As industrial engineers we must provide solutions that insure local industrial optimization does not come at the expense of global optimization and sustainability. In a world where natural resources are dwindling and human resources are growing exponentially, the traditional industrial engineering notion of efficiency that encourages higher natural resource consumption per labor hour, seems woefully out of date and dangerously unsustainable. The key to our sustainable future is proving that industrial and environmental efficiency are not opposing objectives, rather, they are the same objective.

This study sought to understand if, in fact, manufacturers were evolving to this modern view of industrial efficiency by implementing both Lean and Green manufacturing systems. By showing how leading Lean manufacturers are embracing and benefiting from Green manufacturing, this research will encourage further integration and broader implementation of Lean and Green manufacturing systems. I believe that a single integrated Zero Waste Manufacturing system will simultaneously reduce the environmental impact of manufacturing while assuring economic success, thus fulfilling the main objectives of Industrial Ecology and Sustainable Development.

References

- Ahuja, G. (1996). Does It Pay to Be Green? An Empirical Examination of the Relationship Between Emissions Reduction and Firm Performance. *Business Strategy and the Environment*, 5 (1), 30-37.
- Allerton, H.G. III (1990). Hazardous Waste Minimization: Source reduction in the aerospace industry. *Journal of Environmental Health* 53 (4): 28- 29
- Amaoke-Gyaampah, K., J.R. Meredith (1989). The operations management research agenda: an update. *Journal of Operations Management* 8 (3): 250-262
- Arrow, K.J. (1974), *The Limits of Organization*, Norton, New York, NY
- Barbera, A.J. and V.D. McConnell (1990), The Impact of Environmental Regulations on Environmental Performance: Direct and Indirect effects. *Journal of Environmental Economics and Management* 18:50-65.
- Boerner, C. & Chilton, K. (1994). The Folly of Demand Side Recycling. *Environment*: 36(1): 7-33
- Byers, R.L. (1992). Regulatory Barriers to Pollution Prevention. *Pollution Prevention Review* 4: 19-28
- Cattanach, R.E., Holdreith, J.M., Reinke, D.P., Sibik, L.K.(1995) *Environmentally Conscious Manufacturing and Marketing*, Chicago, IL: Irwin.
- CEEM Information Services (1995). *International Environmental Systems Update*, 2 (4)
- Chase, R.B. (1980). A classification and evaluation of research in operations management. *Journal of Operations Management* 1 (1) 9-14
- Chase, R.B., E.L. Prentice (1987). Operations Management: a field rediscovered. *Journal of Management* 13 (2) 351-366
- Christiansen, G.B, R.H. Haveman (1981). Public Regulation and the slowdown of productivity growth. *Journal of Environmental Economics and Management* 8: 381-390.

Ciambrone, D.F. (1996). *Waste Minimization as a Strategic Weapon*, Boca Raton, FL: CRC Press.

Corbett, Charles, Kleindorfer, Paul (2001). Environmental management and operations management. *Production and Operations Management*, 10 (2) 107-112.

Corbett, Charles, Kirsch, David (2001). International Diffusion of ISO14001 certification. *Production and Operations Management*, 10, (3) 327 – 343.

Deming, W.E. *Out of the Crisis*, Boston, MA: MIT Press, 1986

Ehrie, C. (1995), *The Green Passport, Resources*

Elkington, J., Hailes, J., Makower, J. (1990). *The Green Consumer*, New York: Viking Books.

EPA (2001). *An Organizational Guide to Pollution Prevention and Waste Minimization*. Office of Research and Development. Washington DC: United States Environmental Protection Agency. EPA625-R-01-003

EPA (2003). *Lean Manufacturing and the Environment*. Office of Solid Waste and Emergency Response. Washington DC: United States Environmental Protection Agency. EPA100-R-03-005

Filippini, R. (1997). Operations management research: some reflections on evolution, models and empirical studies in OM. *International Journal of Production Management*, 17 (7), 656-670

Florida, R. (1996) *Lean and Green: the move to environmentally conscious manufacturing*. Regents of the University of California.

Global Environmental Management Initiative (GEMI) (2000). *ISO14001 Environmental Management System Self-Assessment Checklist*. Washington, DC

Globenet (2000), EMS Registered Companies Database

Goetsch, D.L., Davis, B.D. (2001). *ISO14000 Environmental Management*, New Jersey: Prentice-Hall.

Gore, A. (1992). *Earth in the Balance*. New York: Houghton Mifflin Company

Gunter, P. (1996) *Upsizing: The Road to Zero Emissions*. Sheffield: Greenleaf Publishing

Hamner, Burt (2002) *Environmentally Conscious Design and Manufacturing* (Listserv): University of Windsor.

Harmon, Marion (1994). First There Was ISO9000, Now There's ... ISO 14000. *Quality Digest*.

Hart, S.L. (1997). Beyond Greening: Strategies for a Sustainable World. *Harvard Business Review*, 75 (1), 66.

Hart, S.L.(1995). A Natural-Resource Based View of the Firm, *Academy of Management Review*, 20 (4), 985-1014.

Hart, S., G. Ahuja (1996). Does it pay to be green? An Empirical examination of the relationship between emissions reduction and firm performance. *Business, Strategy and the Environment*, 5, 30-37.

Hawkins, P. (1993) *The Ecology of Commerce*. New York, NY: HarperCollins Publishers Inc.

Hawkins, P. (1999) *Natural Capitalism*. Boston, MA: Little, Brown and Company

Hay, E.J. (1988). *The Just-In-Time Breakthrough*. New York: John Wiley & Sons, Inc.

Hayes, R.H., S.C. Wheelwright (1984). *Restoring our Competitive Edge: Competing Through Manufacturing*. New York, NY: Wiley

Hileman, B. (1993) Curbing Global Warming. *Chemical and Engineering News* 10 (25): 4-5

Hirschorn, J.S., K.U.Oldenburger, (1988). Roadblocks to waste reduction. *The Environmental Forum*: 20-22.

Ichniowski C., K. Shaw, G. Prennushi (1993). *The Effects of Human Resource Management Practices on Productivity*. Columbia University, Carnegie Mellon University, and the World Bank.

International Organization for Standardization (ISO)(2002). *ISO14001 Environmental Management Systems specification*.

International Organization for Standardization (ISO)(1994). *ISO9001 Quality systems: Model for quality assurance in design, development, production, installation, and servicing*.

International Organizations of Standardization (ISO)(2000), *Welcome to ISO Online*. www.ISO.CH. Geneva: International Organization of Standardization.

Ishikawa, K. (1985). *What is Quality Control? The Japanese Way*. Englewood Cliffs, NJ: Prentice-Hall

Jacobs, R.A. (1991). Waste Minimization Part 2: Design Your Process for Waste Minimization. *Chemical Engineering Progress*. 6: 55 – 59.

Jensen, R. (1982), Adoption and Diffusion of an Innovation of Uncertain Profitability. *Journal of Economic Theory* 27 (2): 182-193

Juran, J.M., F.M. Gryna Jr. (1988). *Juran's Quality Control Handbook*. New York, NY: McGraw Hill

Katin, R.A.(1991) Waste Minimization Part 3: Minimize Waste at Operating Plants. *Chemical Engineering Progress*. 7: 39 - 41

Kenny, D. (1979) *Correlation and Causality*. New York: John Wiley & Sons.

Keppel, G., Zedek, S. (1989) *Data Analysis for Research Designs: Analysis of Variance and Multiple Regression/Correlation Approaches*. New York: W.H. Freeman and Company.

King, A., Lenox, M. (2001), Lean and green? An empirical examination of the relationship between lean production and environmental performance. *Production and Operations Management*, 10 (3), 244-257

Krafcik, J.F. (1988). Triumph of the Lean Production System, Sloan Management Review. *Sloan Management Review*. 30 (1) 41-52

Lamming, R. (1993). *Beyond Partnership: Strategies for Innovation and Lean Supply*, London: Prentice-Hall

Lean Enterprise Institute (LEI)(2003). *Lean Lexicon: Terminology for Lean Thinkers*. Brookline, MA: LEI

Lewis, T.A.(1993) Waste Not, Want Not. *National Wildlife* 4: 20 - 23

Liefset, R. (2000) *Journal of Industrial Ecology*. College of Forestry, Yale University, 3(4)

MacDuffie J.P. (1991). *Beyond Mass Production: Flexible Production Systems and Manufacturing Performance on the World Auto Industry*, Unpublished Dissertation, Massachusetts Institute of Technology.

MacDuffie, J.P. and J. Krafcik (1992). *Transforming Organizations: Integrating technology and human resources for high-performance manufacturing*. New York: Oxford University Press: 209-226.

MacDuffie J.P. (1995). Human resource bundles and manufacturing performance: organizational logic and flexible production systems in the world auto industry. *Industrial Labor Relations Review*, 48 (2), 197

Maxwell, J., S. Rothenberg, and B. Schenk (2001), *Does Lean Mean Green? The Implications of Lean Production for Environmental Management*, Working Paper, MIT, Cambridge, MA.

McCarthy, J.E. (1992) Packaging Waste: Can the U.S. learn from other countries? *Biocycle*. 10: 80 - 83

Meadows, D.H., Meadows, D.L., & Randers, J. (2004) *Limits To Growth: 30 Year Update*. Chelsea: Green Publishing Co.

Melnyk, Steven A.; Sroufe, Robert; Calantone, Roger J. (2003). Assessing the impact of environmental management systems on corporate and environmental performance. *Journal of Operations Management*, 21, 329-351.

Miller, J.G., M.B.W. Graham (1981). Production/operations management: agenda for the 80s. *Decisions Science* 12 (4) 547-571

Monden, Y. (1983). *Toyota Production System*. Atlanta: Institute of Industrial Engineers

Montabon, Frank; Melnyk, Steven A.; Sroufe, Robert; Calantone, Roger J. (2001) ISO 14000: Assessing Its Perceived Impact on Corporate Performance. *Journal of Supply Chain Management*, 2 (36), 2-4

Morris, S.A. (1997). Environmental pollution and Competitive Advantages: An exploratory study of U.S. industrial-goods manufacturers. *Academy of Management Proceedings*, 411-415.

Moxen, J., Strachan, P.A., (1998). *Managing Green Teams: Environmental Change in Organisations and Networks*. Greenleaf: Sheffield.

National Academy of Engineering, (1997) *The Industrial Green Game*. Washington DC: National Academy Press.

National Geographic (2004). *Global Warming*, 206 (3), 1-96

Neely, A. (1993). Production/operations management: research process and content during the 1980s. *International Journal of Operations and Production Management*. 13 (1) 5-18

Office of Policy Planning and Evaluation (1991). *Report on the U.S. Environmental Protection Agency's Pollution Prevention Agency*, Washington, DC: The Environmental Protection Agency.

Ohno, T. (1988). *Toyota Production System-Beyond Large Scale Production*. Cambridge, MA: Productivity Press

Osterman P., (1994) How Common is Workplace Transformation and Who Adopts It? *Industrial Labor Relations Review*, 47 (1): 2

Panizzolo, R. (1998). Applying the lessons learned from 27 lean manufacturers: The relevance of relationships management. *International Journal of Production Economics*, 55, 223-240

Phillips, E.J. (1993) Waste Minimization and the EPA: Hidden Opportunities. *Industrial Engineering*. 3: 22-23

Prokop, M.K. (1993) *Managing to be Green*. San Diego: Pfeiffer & Co.
Rittmeyer, R.W. (1991) Waste Minimization Part 1: Prepare an Effective Pollution Prevention Program. *Chemical Engineering Progress* 5: 56 - 62

Roddick, A. (1991) *Body and Soul*. New York: Crown Trade Paperbacks
Ross & Associates (2000). *Pursuing Perfection: Case studies examining lean manufacturing strategies, pollution prevention, and environmental regulatory management implications*. Seattle, Washington

ROHS (2006) *Website for ROHS compliance*. www.rohs.gov.uk/

Rothenberg, Sandra, Pil, Fritz, Maxwell, James (2001). Lean, green, and the quest for superior environmental performance. *Production and Operations Management*, 10, 228 – 244

Roy, M. (1988). *How We Are Learning to Pollute Less: Pollution Control, Organizational Culture, and Social Learning*, Doctoral Thesis, Cambridge, MA: Harvard University.

Ruckelshaus, W.D. (1990). Free-market opportunity begets environmental change. *Business Week*: June, 35 - 104

Russo, Michael (2001). *Institutional Change and Theories of Organizational Strategy: ISO14001 and Toxic Emissions in the Electronics Industry*. Department of Management, University of Oregon, Eugene, OR.

SAE (1999). J4000: Implementation of Lean Operation Standard. Warrendale, PA: Society of Automotive Engineers. November.

Sakakibara, S., B.B. Flynn, R.S. Schroeder, W.T. Morris, (1992). *The impact of just-in-time manufacturing and its infrastructure on performance*. Working Paper 92-8. Minneapolis: University of Minnesota

Saunders, T. (1993) *The Bottom Line of Green is Black*. New York: Harper Collins Publishers.

Scallon, Monica; Sten, Mark J. (1997) Environmental Positioning for the Future: A Review of 36 Leading Companies in the Pacific Northwest Region of the USA. *Greening the Boardroom*. Sheffield: Greenleaf Publishing, 1997.

Schermerhorn, J.R., (1989) *Management for Productivity*. New York, NY: John Wiley & Sons, 1989

Schmidheiny, S. (1992) *Changing Course*. Cambridge: MIT Press

Schronburger, R.J.(1982). *Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity*. New York, NY: The Free Press

Shingo, S., (1989). *A Study of the Toyota Production System: From an Industrial Engineering Viewpoint*. Portland, OR: Productivity Press.

Shingo (2003). *Shingo Prize for Excellence in Manufacturing: Application Guidelines 2003 – 2004*. College of Business, Utah State University, Logan, Utah.

Skinner, W. (1974). The Focused Factory, *Harvard Business Review*, 52, 113-121

Smith, D. (2005). *to be of use*. Novato, CA. New World Library.

Society of Manufacturing Engineers (SME)(2006) *Lean Certification Website*
www.sme.org/leancert

Tchobanoglous, G., Theisen, H., Vigil, S., (1993) *Integrated Solid Waste Management*. New York, NY: McGraw-Hill, 1993

The World Commission on Environment and Development. *Our Common Future*. Oxford: Oxford University Press, 1991

Unknown (1990). Special Advertising Section: Earth. *Business Week*, June, 82 - 121

U.S. Census, (2003). Current Industrial Reports: Pollution Abatement Costs and Expenditures. U.S. Bureau of Census. Washington, DC: U.S. Government Printing Office

USOTA, (1994). Competitive Challenges and Business Opportunities. *Office of Technology Assessment*. Washington, DC: National Academy Press

Wallace, D. (1995). *Environmental Policy and Industrial Innovation: Strategies in Europe, the U.S., and Japan*. London: Royal Institute of Affairs, Earthscan Publications Ltd.

Watts, R.I. (1990). D.O.E. seeks new ideas for waste reduction. *Journal of Environmental Health* 53 (4): 7

Womack, J.P., D.T. Jones, et al. (1990). *The Machine that Changed the World*. New York, NY: Rawson Associates.

Womack, J.P., D.T. Jones (1994). From Lean Production to the Lean Enterprise. *Harvard Business review*, 72, 93 -103.

Womack, J.P., Jones, D.T., (1996). *Lean Thinking*. New York, NY: Simon and Schuster.

APPENDICES

Appendix A: Expanded Literature Review

Shingo Prize Achievement Criteria

The Shingo Prize recognizes organizations that use world-class manufacturing strategies and practices to achieve world-class results. All applicants who receive a site visit will be publicly recognized as Finalists. Recipients will be selected from this prestigious group.

The Shingo Prize achievement criteria provide a framework for identifying and evaluating world-class manufacturing competence and performance. The criteria comprise a business systems model for manufacturing excellence, organized into five principle sections as pictured on the previous page.

The world-class strategies and practices that are referred to in the criteria are presented in sections I through III of these guidelines. World-class results are discussed in sections IV and V. There are expected measurements for quality, cost, delivery and business results. Any exceptions to reporting the expected measurements should be reviewed with a representative from the Shingo Prize office.

Shingo Prize applicants must prepare an Achievement Report that details key activities and results for each section of the Achievement Criteria based on relevant facts and data spanning a period of three years or longer should be reported. Each subsection's point values serve as a guide to determine the proper amount of material to provide.

ENABLERS

LEADERSHIP CULTURE & INFRASTRUCTURE

(Section Total: 150 Points)

Implementing world-class strategies and practices requires an aligned management infrastructure and organizational culture. This section examines the management systems and organizational culture, the inputs or enablers in a systems model that are necessary to deploy world-class practices and achieve world-class performance. The two elements evaluated are leadership and empowerment.

A. LEADERSHIP

(75 POINTS)

This subsection is designed to evaluate leadership at all levels of an organization with regard to application of world-class strategies and core business system practices that drive world-class results. Leadership creates an organizational culture and infrastructure that aligns the company's mission, strategy and policy to deploy lean/world-class practices and achieve world-class results.

Please discuss how your organization uses leadership to deploy world-class and lean strategies and practices to achieve world-class results. Examples of the items that could provide evidence in this section include, but are not limited to:

- Statements of vision, mission, values, strategies and goals
- A planning process for establishing and deploying vision, mission, values, strategies and goals (e.g., Hoshin Kanri, Policy Deployment, Management By Objective, etc.)
- Allocation of resources for deploying vision, mission, values and strategy
- Sustained personal commitment and involvement of all the organization's managers to find and eliminate waste, muda, or any non value-added activities and costs
- Knowledge management system and business results that are deployed to all levels of the company

Appendix A. (Continued)

- Communication and measurement of quality, cost and delivery standards throughout the organization
- An organizational philosophy that encourages and recognizes innovations, entrepreneurship and improvements wherever they originate in the organization

B. EMPOWERMENT (75 POINTS)

This subsection is designed to evaluate the degree of employee empowerment to effect change within the organization, particularly as it relates to deploying world-class strategies and practices. Employee involvement and empowerment means that a highly specific environment exists that unleashes and fully utilizes each person's talents, skills, diversity and creativity through individual commitment and team effectiveness. This evolutionary process gives each employee the opportunity to feel confident, to be heard and to be respected. The result is job enrichment, maximum productivity, achievement of organizational objectives and a continued commitment to employee development.

Please discuss how your organization uses employee involvement and empowerment to deploy world-class strategies and practices. Examples of items that could provide evidence for this section include, but are not limited to:

- Magnitude of employee training in world-class practices, separating orientation training from regular employee training
- Use of teams (e.g., corrective action teams, cross-functional teams, process improvement teams and/or self-directed teams) to deploy world-class strategies and practices to achieve world-class results
- Suggestion systems or other mechanisms that demonstrate management's willingness to receive innovative and/or improvement ideas from all sources
- Recognition and reward systems for the company/plant (e.g., gainsharing), teams and/or individuals contributing to demonstrated improvements
- Company procedures that facilitate all employees sharing problems and exchanging ideas with customer and/or supplier employees
- Measures that document employee satisfaction and morale such as employee turnover, absenteeism and employee survey results
- Efforts to maintain an ergonomic, clean and safe work environment for all employees
- Specific safety program results, such as, reportables and lost time.

CORE OPERATIONS MANUFACTURING STRATEGIES & SYSTEM INTEGRATION (Section Total: 450 Points)

This section focuses on the core manufacturing strategy, practices and organizational techniques deployed to achieve world-class results. It should provide information about the value chain practices and techniques the company uses to achieve world-class results.

A. MANUFACTURING VISION & STRATEGY (50 POINTS)

This subsection requires an outline of the company's manufacturing vision and strategy as it relates to the selection and use of the specific methods, systems and processes detailed in subsections B, C, and D of this section.

B. INNOVATIONS IN MARKET SERVICE & PRODUCT (50 POINTS)

This subsection is designed to evaluate a company's market service and product innovation. Any available information regarding competitors' benchmarking of services and products should be included. Two potential approaches could be pursued: (1) innovative efforts to

Appendix A. (Continued)

reduce the cost of existing product(s) and product development; and (2) innovations in market service. Both approaches are viewed as enhancing business growth and performance. The second approach generally applies to companies that are primarily assemblers or those who manufacture a commodity-type product with limited opportunity for new product development.

The methods and processes documenting market service and product innovation may include, but are not limited to:

- Verifiable cost reductions in logistics, sales, service, post sales service, technical support, etc. for an assembler or a manufacturer of a commodity product
- Using quality function deployment, concurrent or simultaneous engineering, etc. for product development
- Benchmarking competitors' products and services
- New market development and current market exploitation
- Design for manufacturability, testing, maintenance, assembly, etc.
- Variety reduction
- Converting a commodity-type product to a more specialty differentiated product
- Innovations in market service and logistics
- Broadening sales mediums to include avenues such as e-commerce, the internet, etc.

C. PARTNERING WITH SUPPLIERS/CUSTOMERS & ENVIRONMENTAL PRACTICES (100 POINTS)

This subsection is designed to evaluate the company's efforts to deploy world-class practices by partnering with suppliers and customers, and to assess how well the company integrates suppliers and customers into the value-creation process. Discuss how your organization uses partnering to deploy world-class practices and/or to achieve world-class results. Documentation in this section may include but is not limited to:

- The integration of the company, its suppliers and its customers in establishing value-creating methods and practices across company boundaries in production or product development
- Distribution and transport alliances to insure product quality and productivity
- Initiatives regarding environmental issues (i.e., recycling, reducing industrial waste, ISO 14000, etc.)
- Supplier satisfaction measures
- Union partnership initiatives
- Benchmarking projects for process improvement.
- Cooperative endeavors with schools and training organizations to ensure a qualified workforce
- Cooperative community endeavors that demonstrate the company and its employees are socially responsible

D. WORLD CLASS MANUFACTURING OPERATIONS & PROCESSES (250 POINTS)

This subsection focuses on deploying the world-class/lean manufacturing practices necessary to achieve world-class performance.

This section could include intermediate results and anecdotal evidence concerning the techniques and practices listed below.

Please discuss how your organization uses any of the world-class/lean manufacturing practices or other similar activities. Documentation could include, but is not limited to:

- Time-based or just-in-time manufacturing
- Systematic identification and elimination of all forms of waste
- Value Stream Mapping

Appendix A. (Continued)

- Value Analysis
- 5S Standards and Disciplines
- Standardized work
- Total productive, preventive or predictive maintenance
- Quick changeover or setup reductions (SMED)
- Source inspection and poka-yoke
- Visual workplace/visual manufacturing
- Cellular manufacturing
- Continuous flow
- Multi-process handling and automation (jidoka)
- Pulling work through the production sequence (kanban)
- Distributing work intelligently and efficiently (heijunka or load leveling)
- Six sigma or statistical process control
- Theory of constraints
- Breakthrough kaizen events (kaikaku)
- Tools of quality (i.e., pareto charts, storyboarding, cause and effect diagrams, 5-why's or similar problem-solving techniques)
- Production Process Preparation (3P)

NON-MANUFACTURING SUPPORT FUNCTIONS

(Section Total: 100 Points)

This section is designed to evaluate (1) the degree of integration between manufacturing and all non-manufacturing functional units; and (2) the extent to which improvement techniques and strategies have been applied in non-manufacturing functions up and down the value stream (new product development efforts are detailed in Section IIB and need not be repeated here). Non-manufacturing support functions may include accounting, finance, human resources, sales and marketing, materials, purchasing, quality, MIS, etc. Address only those non-manufacturing functions that fall under the scope or control of the applicant site.

Evidence could include, but is not limited to, a discussion of:

- Alignment of non-manufacturing functions to support the manufacturing function
- The integration of non-manufacturing functions with manufacturing
- Incorporation of continuous improvement in the mission or vision statements, goals or strategies of all non-manufacturing functions
- Elimination of waste or non-value-added activity in all functional units of the organization (e.g., closing of financial books in hours rather than days)
- Commitment to continuous improvement projects and/or change processes in long-range plans, capital budgets, training and human resource development, marketing plans and strategic reviews by all functional business units

OUTPUT RESULTS

QUALITY, COST & DELIVERY

(Section Total: 225 Points)

This section is designed to evaluate the outputs of the core business systems or the performance of the world-class/lean practices described in sections II and III of the criteria. Evidence in this section includes multiple measures of quality, cost and delivery. Each measurement presented, should be documented with three or more years of data. When measurements have been in place less than three years, present whatever data is available. Data reported should show, to the extent possible, not only the trend, but also the performance level attained and potential industry benchmark comparisons.

Appendix A. (Continued)

The current goal for each key measure should be reported as well. Note that there are expected measurements for quality, cost, delivery and business results. Any exceptions to reporting the expected measurements should be reviewed with a representative from the Shingo Prize office. Results data reported may be based on either "profit or cost center" policy. An expected measures spreadsheet and definition elaboration will be provided to each applicant upon notification of an intent to apply. The spreadsheet must be included in the Achievement Report. Adjustments for extraneous factors such as inflation and changes in product mix should be clearly documented.

A. QUALITY & QUALITY IMPROVEMENT (75 POINTS)

The objective of the quality & quality improvement category is to insure that no human or machine errors ever get into customers' hands and that in-process defects are continually being reduced. The goal is zero defects. Both trend and level data should be presented and the basis/definition for all quality measurements should be reported.

Expected measurements:

- Rework as a percent of sales or production costs
- Customer rejects due to quality (ppm)
- Finished product first pass yield and percentage
- Unplanned scrap rate(s)

Supplemental data could include:

- Overall cost of quality as a percent of sales, total manufacturing cost or other appropriate baseline
- Process variation measures
- Warranty cost as a percent of sales
- Other appropriate measures

B. COST & PRODUCTIVITY IMPROVEMENT (75 POINTS)

The purpose of the measured cost and productivity improvement category is to assess the improvement trend and level in cost and productivity. Both trend and level data should be presented and the basis/definition for all cost and productivity measurements should be reported.

Expected measurements:

- Total inventory turns separated as appropriate into raw, WIP and finished goods.
- Value added per payroll dollar (sales minus purchased goods and services divided by total payroll dollars)
- Manufacturing cycle time (start of product production to completion)

Supplemental data could include:

- Physical labor productivity (units/direct hour)
- Energy productivity
- Product cost reduction
- Percent machine uptime
- Changeover reductions
- Resource utilization (e.g., vehicles, plant and warehouse floor space, etc.)
- Transport and logistics effectiveness and cost
- Other appropriate measures

C. DELIVERY & SERVICE IMPROVEMENT (75 POINTS)

Appendix A. (Continued)

The purpose of the delivery and service improvement category is to identify whether customers are getting what they need in the time and quantity necessary. Both trend and level data should be presented and the basis/definition for all delivery and service measurements should be reported.

Expected measurements:

- Percent of line items shipped on-time (define on-time window) and/or percent of complete orders shipped on-time (define on-time window)
- Customer lead time (order entry to shipment)
- Premium freight as a percent of production costs

Supplemental data could include:

- Mis-shipments
- Warranty response and service
- Other appropriate measures

BUSINESS RESULTS

(Section Total: 75 Points)

This section is intended to evaluate the outcomes of quality, cost and delivery on customer satisfaction and business results. For each measurement presented, three (3) or more years of results should be documented.

Customer Satisfaction -

Evidence of customer satisfaction may be presented through any valid approach used by the company. Survey data should describe sample size, survey format, frequency and efforts to avoid bias. Measures reported must be clearly defined and could include, but are not limited to:

- Market share
- Reorder rate
- Customer survey results
- Customer awards
- Customer audits
- Field performance data
- Other appropriate measures

Profitability -

Measures of level and trend should be clearly defined and should document the unit's overall relevant business financial attainment.

Expected measurements:

- Operating income on sales ratio
- Operating income on manufacturing assets ratio

Supplemental data could include:

- Reductions in fixed and/or variable costs
- Cash flow
- Product line margins
- Other appropriate measures

Appendix A. (Continued)

Business Prize Scoring System

The Shingo Prize Examiners review business applications based on two evaluation dimensions: (1) Strategy & Deployment and (2) Results. Each of the Achievement Criteria's subsections require applicants to furnish information relating to one or both of these dimensions. Sections I through III refer primarily to information on Strategy & Deployment. Sections IV and V refer primarily to overall organizational results. However, it is fully appropriate to include "intermediate" results (number of leadership initiatives, number of teams, team participation rates, number of suggestions per year, cycle time reduction in a specific process, etc.) in sections I through III.

Specific factors relating to each evaluation dimension are described below.

Strategy & deployment

Strategy is the means, processes or methodologies an organization pursues to achieve its business plan and manufacturing goals. Deployment is the action the organization takes to achieve the intended strategy. Scoring is based on:

- the acceptance and use of Shingo's comprehensive view of "waste" as any non-value added activity and its prevention as the only path
- the degree of organizational focus on value-added activities
- the existence of goals focused on continuous improvement and world-class manufacturing
- the understanding of the importance of business processes as an area for analysis and improvement
- the effective use of appropriate tools, techniques and technologies in a variety of improvement initiatives
- the demonstrated cooperation and integration between employees' efforts at all levels

Results

Results are an organization's demonstrated achievements in reaching each manufacturing and business goal. Scoring is based on:

- the demonstrated improvement trend in each key area
- the level of performance in each key area
- the use of outside benchmarks in intelligent goal setting
- the choice and use of appropriate measures for each specific purpose, and the proper technical adjustments
- the intelligent use of the measured results to stimulate further improvement

Scoring Guidelines

When using this scoring grid, select the quadrant that tends to best describe the company's current practice based upon the individual descriptors, then qualitatively decide whether the current practice is high, mid, or low. A qualitative percentage is selected and multiplied by the point value of the criteria element to determine a current practice score.

Strategy & deployment

Organizations which fully match the descriptors would score at the top of the indicated range, etc.

100%	<ul style="list-style-type: none">• tenacious strategic focus on high-value-added processes and issues• major, fully completed waste prevention applications that could be considered best practices examples• clear and ingrained use of all appropriate human and technical resources in an integrated manner
I	
80%	

Appendix A. (Continued)

80% 60%	<ul style="list-style-type: none"> • recognition of strategic priorities with frequent consideration beyond day-to-day issues • many good waste-prevention projects, some of which are around key processes and issues • frequent use of appropriate human and technical resources to reach beyond the conventional solution, but occasional problems in getting integrated action
60% 40%	<ul style="list-style-type: none"> • existence of some strategic ideas but rarely applied systematically • a few good waste-prevention/reduction applications, more are planned as time permits • some use of human and technical resources beyond conventional, but difficult to get integrated cooperation and action
40% 20%	<ul style="list-style-type: none"> • no evidence of strategic focus; reactive only to day-to-day issues • minor, incomplete, limited-value applications of waste reduction • no evidence of use of human and technical resources in problem solving

Results

Organizations which fully match the descriptors would score at the top of the indicated range, etc.

100% 80%	<ul style="list-style-type: none"> • excellent improvement trends in key strategic areas and within the waste-prevention projects • high and predictable levels of performance with active programs based on goal setting • creative choice of appropriate indicators with demonstrated validity • evidence of ingrained, routine feedback of results to those responsible for improvement
80% 60%	<ul style="list-style-type: none"> • generally good improvement trends in the key strategic areas and in improvement projects • good level of performance in most areas and projects; some attention to goal setting • appropriate measures used with demonstrated validity • good evidence of feedback of results to those involved in improvement on a regular basis
60% 40%	<ul style="list-style-type: none"> • good improvement trend in some key areas and applications • reasonable-to-good level of performance in some areas and applications • adequate choice of measures used but little demonstrated validity • little evidence of results feedback as a routine
40% 20%	<ul style="list-style-type: none"> • no apparent improvement trend in key areas; mixed results in applications • levels of performance that are either low or not predictable • poor choice of measures and insufficient use • no evidence of systematic feedback of results

Eligibility

The Business Prize may be awarded to any qualifying applicant in each of the following categories.

1. Large manufacturing companies, which can include:
 - Whole Company
 - Division or Business Unit
 - Single Plant
2. Small manufacturing companies, which can include:
 - Whole Company

Appendix A. (Continued)

- Division or Business Unit

Manufacturing entities in existence three or more years, located and operated in the United States, Canada or Mexico that conform to the U.S. Standard Industrial Classification (SIC) of Manufacturing are eligible to apply for the Prize. For individual entities engaged in both service and manufacturing, classification is determined by the larger percentage of sales. Additional eligibility requirements that an entity interested in challenging for the Shingo Prize must meet include the following:

- If a single applicant business entity individually comprises more than 50 percent of the business unit, then the entire business unit must be included in the application, unless the business unit can provide a substantive justification that the remaining entities are not integral to the operation of the business unit or applying entity.

Questions regarding eligibility should be clarified prior to submitting the Intent to Apply Form.

- A Prize Recipient is ineligible to re-apply for the Prize for five years.
- At least 50% of the business' revenue must be derived from manufacturing activities.

Small businesses are defined as independent corporate entities with fewer than 500 full-time equivalent employees. Small businesses may challenge for the Prize provided that the above provisions are met. A division or business unit of a small company may apply as a separate entity. In order to apply, the entity must be operated essentially as a complete business.

Large businesses are defined as corporate entities with 500 or more full-time equivalent employees. Large business entities may challenge for the Prize according to the following provisions.

- Manufacturing business entities (subsidiaries, business units, divisions and plants) wishing to apply must have at least 50 full-time equivalent employees and have clear lines of distinction from other organizational units. Separate organizational units of a large business may compete individually, but must apply in the large business category, regardless of the number of employees in the specific unit.
- Multiple entities within one company, subsidiary, business unit, or division may apply individually in the same year, unless the applying entities together comprise a clear majority of the next larger business unit (i.e., company, subsidiary, business unit or division), in which case the application will automatically be considered on the basis of the larger entity.

APPLICANTS NEED TO PROVIDE

1. Intent to Apply Form - organizational information sufficient to determine eligibility (see page 19).
2. Achievement Report - written documentation of the company's efforts and achievements in manufacturing excellence conforming to the criteria outlined in these guidelines. The Achievement Report should generally not exceed 100 pages.

Examination Process

All applicants who receive a site visit will be publicly recognized as Finalists. Recipients will be selected from this prestigious group.

The examination process has four steps. First, Achievement Reports are submitted and distributed for review by members of the Board of Examiners. The review will occur prior to

Appendix A. (Continued)

September 1, 2003. High-scoring applicants are designated as Finalists and will receive site visits. Second, site visits will be conducted between approximately September 1st and November 22nd each year. Third, based on the application review and the site visit results, the Board of Examiners will recommend Finalists to the Shingo Prize Board of Governors to become Prize Recipients. Finally, the Board of Governors reviews the recommendations and may either ratify or reject the Board's recommendations. Companies will be notified by the end of January.

Decisions made by the Board of Governors are final and are not subject to appeal. Business applicants will receive written feedback on notable accomplishments and opportunities for possible improvement based upon the items reviewed during the Achievement Report and the site visit.

SITE VISITS

Candidates for the Shingo Prize will receive a site visit by a team of examiners. A single facility application will generally require a team of five (5) to eight (8) examiners.

The primary objective of the site visit is to verify, clarify and amplify the information contained in the Achievement Report. In terms of clarification, companies should be prepared to update all metrics reported in their Achievement Report during the site visit.

Appendix A. (Continued)

The Russo Model

Methodology:

Sample:

The study explored the adoption and impact of ISO 14001 within a sample of electronics plants, broadly defined. The plant, or facility, was chosen as the unit of analysis for two reasons. First, it is facilities—not firms—that are registered under ISO 14001. The ISO 14001 registration process was designed specifically to operate at this level, as it was patterned after the ISO 9000 quality standards (Tabor, Stanwick, and Uzumeri, 1996). Second, data within the Toxic Release Inventory is organized at the plant level, and aggregation beyond that level creates imprecision. In order to balance the need for a viable sample size with comparable industry environments, six segments of the electronics industry were selected for analysis: SIC 3571 (Electronic computers), SIC 3651 (Household audio and video equipment), SIC 3661 (Telephone and telegraph equipment), SIC 3671 (Electronic tubes), SIC 3672 (Printed circuit boards), and SIC 3674 (Semiconductors and related devices). Thus, there is a high degree of commonality to the sample, responding to criticism of studies with samples that are too dispersed (Griffin and Mahon, 1997). The numbers of observations for the two studies are shown in Table 1. I used as the population all facilities in these segments where manufacturing took place and which employed at least 100 persons. Data furnished by Dun and Bradstreet listed 1104 such establishments.

A university survey research center randomly selected and contacted facilities from the set of 1104 facilities in early 2000. A total sample of 316 facilities provided interview data. Given that 95 of the original 1104 sites were not actually manufacturing sites or were used for other lines of business, the interviewed sample consisted of 31.3% of the population. All facilities were contacted multiple times, and the main reason for non-response was inability to get to the respondent either due to absence or having an answering machine respond to all interview attempts. Refusals by respondents were a relatively minor occurrence, at roughly 5% of non-respondents. When contacting firms, in order to avoid biases, interviewers did not leave phone messages, as this might have affected the chance of a return phone call. The level of success we enjoyed might be due to the relative lack of knowledge about ISO 14001, the desire of environmental managers to receive copies of the results of this study, or a desire to improve the network among environmental professionals. In early 2001, a second wave of surveys was sent to firms that had not yet registered to ISO 14001 to ascertain whether or not they had done so.

Of the 316 facilities that were contacted, a number was dropped from each analysis because the interviewee did not provide information on all variables that were used in analyses. In addition, for the study of toxic releases, an additional 196 facilities had to be handled differently because they did not produce enough toxic emissions for any effluent to report to the Environmental Protection Agency (This raises the issue of selection bias, with which is explicitly addressed below). Table 1 provides a summary of the available facilities and observations for the adoption study and emissions study, organized by Standard Industrial Classification area.

Appendix A. (Continued)

Study Period. I used the years 1996 through 2000 for the study of ISO 14001 adoptions. Although the ISO 14001 standards were finalized in late 1996, their general nature was well known prior to that point, and in fact several respondents claimed to have “registered” earlier in 1996. This is feasible, since the drafts of ISO 14001 were available by 1995 (Epstein, 1995). For the emissions study, as toxic emissions data is only available through 1999, that year is the last one used in that analysis.

Variables

Dependent Variable. To explore whether or not environmental performance is influenced by ISO 14001 registration, I needed a defensible measure of environmental performance. The development and use of metrics in this area are a challenge (Committee on Industrial Environmental Performance Metrics, 1999). One candidate, environmental reputation scores, are highly correlated with financial returns (Brown and Perry, 1995) and calculated at the firm, not facility level. Fines and/or spill performance might also be used, but these are episodic in nature, and might not pick up the continuous nature of emissions performance. A better approach than either of these is to use data from the Environmental Protection Agency’s Toxic Release Inventory, or TRI. This database contains information on the release of 579 individually listed chemicals and 28 chemical categories on a facility-by-facility basis.

Using TRI data raises several methodological issues. The first issue arises from the wide variation of toxicities of the substances that are emitted by plants. Some are highly and immediately toxic, while others are of less concern. In order to address this problem, I used a method originated by King and Lenox (2000). This consisted of dividing each chemical by a quantity used by the EPA to set an upper limit on what could be discharged without having to report an incidence of a spill to the EPA. These “reportable quantities” vary with the toxicity of a given substance; the more toxic the substance, the lower the reportable quantity. Reportable quantities run from 1 to 5000 pounds. At the limit, a report must be made if just 1 pound of a highly toxic chemical is emitted (for example, methyl isocyanate, which was released in Bhopal, India, in 1984). For a given facility and year, I divided each chemical emitted by a facility by these reportable quantities, and then aggregated across the chemicals released at a facility to produce what is called a “release index.” Because this data was highly skewed, the logarithmic transformation (after adding 1) was taken prior to using this variable and its lagged values. Using the dependent variable and its lag effectively estimates changes in emissions from year to year.

Independent Variable. For the study of emissions, the independent variable was a dichotomous variable, coded 1 if the facility had ISO 14001 registration, and 0 otherwise. Because information on the month and year of registration was on hand, a facility was considered registered for a year if it was registered for at least half of the year. If it registered later, it was coded as being registered during the next year. Once registered, all facilities in the sample stayed registered in subsequent years.

In using the date that an EMS was operational, a measurement issue arose. In order to receive ISO 14001 certification, an EMS must be in place at the facility. Therefore, a confound would exist if an EMS that was created as part of ISO 14001

Appendix A. (Continued)

registration was treated equally with those that existed prior to registration. To address this issue by allowing for time lags, an EMS was coded as being in place if it was operative for at least a full year prior to the year in question. So for example, an EMS that went into effect in 1996 would result in the EMS variable being coded 1 from 1998 forward. For earlier years, the variable would be coded 0, as it would for any facility that had no EMS.

Control Variables. It was important to account for the influence of other factors on ISO 14001 adoption and toxic emissions. The effect of size was controlled by including the number of employees at each facility. It would have been better to obtain actual outputs for facilities, but this is classified information. Instead, I used an estimate for the number of manufacturing employees for each of the years 1996 through 1999, taken from interviewees. Also included was the age of the plant, to try to pick up any influence of its vintage. Because plants routinely go through upgrades, I tried to reduce the impact of variation among older plants by employing the natural logarithm of plant age in calculations.

To pick up the effect of overall environmental regulation in the state, based on Meyer (1995) I included a measure of total toxic releases per dollar of state GDP. Two controls pick up ownership patterns within the sampled firms. Two dummy variables were coded one if the owner of the plant was Japanese or European, and were coded 0 otherwise. Remaining plants were owned by American companies or had corporate parents based in other countries. Press reports suggest that the Japanese embraced ISO 14001 enthusiastically, and some observers have argued that the system may be preferred by European plants to the Eco-Management and Audit Scheme (EMAS) system often used in Europe. Because California is generally viewed as the location of cutting edge manufacturing in this industry, I included in regressions a dummy variable set equal to 1 if the plant was located in California.

Also included were dummy variables for each of the 6 4-digit SIC code groups, omitting SIC 3571 to avoid overdetermination. For one of the analyses of firms reporting TRI emissions, no facilities from SIC 3571 had data, so SIC 3651 was omitted. If there are any inherent differences in the profiles of emissions for industries, these should be picked up by these dummy variables. Finally, I included dummies for the years 1997 through 2000 for the adoption study, and 1997 through 1999 for the emissions study, in both cases omitting 1996 to avoid overdetermination.

Statistical Methods. In the study of ISO 14001 adoptions, event history methods were used to analyze the adoption of ISO 14001 (Tuma and Hannan, 1984). The methodology is specifically developed to analyze discrete events occurring within time. For example, events such as the corporate takeover bids (Davis and Stout, 1992), entry into new markets (Haveman, 1993) and dissolution of strategic alliances (Park and Russo, 1996) have been analyzed with this technique. Essentially, event history methods are well-suited to longitudinal situations where events take place across a specified time period. To the extent that changes in the independent variables are associated with longer or shorter waiting times until

Appendix A. (Continued)

registry occurs, statistical significance is generated. It could be said that event history compares to logistic analysis as pooled, cross-sectional time series analysis compares to cross-sectional analysis. The difference in both cases is that multiple time periods are involved, and each “individual” (here, the facility) contributes an observation to the data set for each time period. The exponential specification was employed to model events.

Because the ISO 14001 standards were basically sketched out by the beginning of 1996, time was measured in months from January, 1996, until registry for a given facility occurs. If no registry occurs, the facility contributes is considered “right-censored,” a situation that event history methods were specifically developed to address. Once registration takes place, a facility is coded as having experienced an event, and removed from analysis in subsequent years. The number of observations does not equal the number of years times the number of facilities for two reasons. In two cases, plants were closed prior to the study period end, and for a larger number of cases, facilities were opened subsequent to 1996. Both of these situations are easily accommodated with the RATE program. For observations for the year 2000, the length of the spells varied. If the facility adopted ISO 14001, the months until adoption were used. For non-adopters, three months was used unless the facility was contacted in the second wave of surveys, in which case, twelve months was used. Both types of non-adopters were considered censored cases.

In estimations of emissions performance, I used the two types of regression analyses to test hypotheses that are described below. There was a potential for heteroskedasticity in the regression, as heteroskedasticity was found in a previous study that used TRI data (Klassen and Whybark, 1999). Two tests for heteroskedasticity in the emissions study were conducted. First, I used the Goldfeld-Quandt test to test whether residuals varied with either the number of employees or toxic emissions. In both cases, the test suggested no relationship. The more general White (1980) test was also applied to the data, and it too indicated that heteroskedasticity was not evident.

A more serious potential problem with the study of emissions concerns the lack of Toxic Release Inventory data for facilities and emissions. Making the situation especially noteworthy is that the chance that data is missing is tied to the level of emissions itself: unless a facility manufactures or processes more than 25,000 pounds or otherwise uses at least 10,000 pounds of any of EPA’s listed chemicals, it does not report to TRI (United States Environmental Protection Agency, 2001). This was the major reason for missing emissions data. A secondary reason and much less frequently-occurring reason was that TRI identification numbers for several facilities could not be found, even after substantial efforts to track down this information. Altogether, missing TRI data occurred for more than half of observations that had all other variables on hand.

It is possible that this situation can produce sample selection bias (Heckman, 1979), because if facilities fail to report to TRI, their emissions reductions will not affect the estimates for emissions. So a sample selection correction was undertaken using a SAS “macro” program designed for the purpose. This program corrects for any selection bias by creating an additional variable, λ , that captures the

Appendix A. (Continued)

effect of emissions on the chance of not reporting to TRI. The coefficient on λ should be positive, based on the fact that the greater the emissions, the more likely is a facility to make a TRI report.

Even with a sample selection bias correction, the number of observations is small relative to the whole sample. In an effort to include all observations in an analysis, a final analysis was conducted with a Tobit approach that could accommodate censored data (Johnson and DiNardo, 1997). This model is appropriate when the dependent variable is only reported when it is above or below some level. In using this model, the data from the many non-reporting facilities can contribute its full richness, rather than acting solely through the sample selection bias variable, λ . In order to conduct this analysis, a key tradeoff had to be made because the missing lagged values had to be modeled. So to estimate the lagged effects, two variables were entered. The first is a dummy variable that is coded 1 if the facility reported data in the last reporting period, and zero otherwise. The second variable picks up the reported emissions themselves, and is set equal to those lagged emissions if reported, and zero otherwise. Together, these variables model a process where reported emissions step upward after a threshold level, and then increase with the level of actual lagged emissions. The analysis used, an option within the SAS LIFEREG routine, explicitly accounts for observations for which the dependent variable is missing.

In all regressions, a fixed effects model was employed. With this specification, a string of dummy variables—one for each facility—is included in the model. These dummy variables have the effect of setting a separate intercept term for each facility, which is a powerful method for accounting for many factors that are specific to the various plants (Hsiao, 1986).

About The Author

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