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Lean Six Sigma as a Source of Competitive Advantage

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LEAN SIX SIGMA AS A SOURCE OF COMPETITIVE ADVANTAGE

by

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BRIGHAM YOUNG UNIVERSITY

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ABSTRACT

LEAN SIX SIGMA AS A SOURCE OF COMPETITIVE ADVANTAGE

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Anecdotal data affirms that companies applying Lean Six Sigma in their operations not only deliver higher quality products and services, but also obtain superior financial results. The goal of this research was to empirically verify anecdotal data. The study proposed to analyze a group of publicly traded manufacturing companies with the intent of verifying if a correlation exists between companies being lean and the attainment of superior returns on investments. The researcher performed a series of statistical tests comparing key Financial Performance Indicators (FPI) extracted from annual reports (10-K) from a large pool of companies. The outcome of this study showed that superior financial rewards result from a systematic application of lean and quality tools.

At the conclusion of this thesis we verified that companies having a business model that stimulates a high level of communication between them and their markets – because they are lean – obtained substantially higher financial advantages when

compared to companies that still followed a more traditional mode of production. The results also revealed that lean companies obtained on average Return on Invested Capital (ROIC) 10% higher than mass producers. Therefore, companies wanting to strategically invest their capital should consider Lean Six Sigma as a source of competitive advantage.

Another strategic insight derived from this study was the recognition of signs of a smart business. Potential investors should look for the presence of lean and quality improvement programs as one sign that capital is being wisely invested to generate value. Another sign is how well historically ROIC have performed against Weighted Average Cost of Capital (WACC). The research revealed that, on average, lean companies had ROIC of 16%. Assuming that the hurdle rate (WACC) for most companies is near 10%, having ROIC of 16% is an incentive to become lean, thus allowing such companies to create value for their shareholders.

Finally, we learned that many factors affect ROIC, namely, brand equity, market positioning, patents, core competency, innovation, leadership, etc. However, the presence of a Lean Six Sigma program in a manufacturing business was a strong positive factor impacting ROIC.

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1 Introduction

1.1 Background

Before the Industrial Revolution initiated in Great Britain in the late 18th century all manufacturing was primarily done manually by craftsmen in shops. The manual production system was characterized by a great variety of products, high quality, and low volumes. The Industrial Revolution created the environment that transformed the way manufacturing was done, converting craftsman into proletariat. These workers gathered from all over Great Britain into a few centers to work in factories. The workers did not own their machines, so they had to work for the industrialist (owner of capital). The resulting production system was characterized by mechanization and a focus on a few products. These products were generally manufactured in high volumes and were notoriously known as being of poor quality.

At the beginning of the 20th century America's manufacturing sector boomed thanks to the application of the ideas of Frederick W. Taylor on Scientific Management. Henry Ford followed Taylor's theory when he initiated automation in his automobile factories in order to reduce production cost and improve productivity. The concepts of assembly line and standardization were introduced into manufacturing, and goods were mass produced while their cost was dramatically lowered. Ford was able to explore the economies of scale by manufacturing fairly complex products, such as cars, and by having a low cost structure, thus being able to pass the cost savings to customers in the form of lower prices. The quintessential example of this new form of production was the initial *Ford Model T*. It only came in black color, and it was very unreliable due to its premature technology.

After the devastations of WWII the United States continued advancing mass production practices and eventually became the largest manufacturing country in the world. During the same period, the Japanese began to rebuild their economy, infrastructure, and industry. Their products were widely known for being inexpensive and for having terrible quality standards. Not too many years later, the Japanese realized that if they wanted to compete against the world class manufacturers, they had to improve their production system. Ironically, the Japanese were more successful than the Americans in applying the quality tools developed by American statisticians. Walter A. Shewhart, W. Edward Deming, and others were sent to Japan right after the war to assist the Japanese reconstruct their economy and former industry (Neave 1990).

Toyota was one of the companies that pioneered the use of some of these quality tools. They created their own quality principles with the primary objective of improving productivity, reducing costs, and providing quality products that eventually overcame the Japanese post-war depression. Toyota's main focus was reduction of waste wherever it may be, and the concept of value creation. The aim of their quality program was to only provide product features which customers would be willing to pay for. Their reasoning was this: if a company could remove all types of waste out of its system and create value according to customer wants, then this company would be able to make high quality products precisely tailored to customer needs. Such a company would not only contribute to create value to its customer base, but also to create value to society (Liker 2004).

1.1.1 Lean and Six Sigma

Toyota called the new philosophy of offering a great variety of high quality products in a very timely fashion the Toyota Production System, or simply Just-in-Time. James P. Womack and Daniel T. Jones, in their book *The Machine that Changed the World*, coined the term "Lean Production" to describe the essence of the Toyota Production System to westerners (Womack and Jones 1996).

The concept of lean manufacturing means that a company only produces what customers want, when they want it, doing so in a timely fashion and with superior quality. Mass customizing production, just like Toyota does, not only delights customers, but also improves the business cash flows, thus helping the company free up some of capital invested in inventory. In turn, the reduction of inventory helps the firm further reduce costs associated with manufacturing overhead and other forms of waste.

The final dimension of the improvement challenge taken up by the Japanese was the implementation of quality tools in order to reduce production variation and defects, while improving the flow of materials and information. The quality tools mentioned above include: Total Quality Management, Statistical Process Control, Theory of Constraints, Six Sigma, etc.

1.1.2 Lean Six Sigma Improve Finances

One of the key points of this work is the importance of synergizing the idea of customer centricity with process improvement as a means to improve financial performance. The consistent application of these concepts, such as streamlining production (lean) and quality improvement, is the basis for companies to achieve market leadership. This happens mainly because the powerful combination of these tools mentioned above produces remarkable financial results.

For instance, Jack Welch, the former CEO who revolutionized General Electric in the past four decades, declared that the program Six Sigma added an estimated benefit on the order of $10 billion in profits during the first five years of its implementation. Dave Burritt, the Six Sigma Corporate Champion at Caterpillar Inc. stated: "Six Sigma and Lean are great complementary approaches for driving process excellence. At Caterpillar, Six Sigma provides the overarching infrastructure, and we supplement its quality methods with Lean tools to accelerate the process velocity" (George 2002) According to the consulting firm George Group, Black Belts save companies approximately $250,000 per project and usually complete an average of two to four projects per year (George 2003).

The mentality of continuous improvement and avoidance of excess was initiated by the Japanese in an attempt to save a country completely destroyed by the war. However, the principles behind this new paradigm can help companies avoid financial distress and make a positive contribution in a very competitive and globalized world. The general feeling among the Toyota leadership and other consultants (management gurus) is that many opportunities still exist to improve systems and save money in every process of every corporation out there. This is the reason why Toyota and many world class companies continue to apply lean production or other similar programs to support their business enterprises (Liker 2004).

1.2 Objective

The goal of this thesis is to successfully demonstrate that manufacturing companies applying lean principles and quality control tools are able to respond better and faster than mass producers to complex market demands. The successful exchange of information between market and producer is what Claude Shannon – the father of Information Theory – defined as efficient communication. Efficient communication in the business management context is the producer's ability to respond precisely and correctly to an unknown message transmitted by the market, which in this case is the customer demand (Shannon 1964 1949).

At one hand, lean companies have a great ability to fulfill market demand because they are flexible and agile, thus being able to easily scale up and down production to accommodate customer needs. At the other hand, mass manufacturers are slower to respond to market demand because of their mass scale mode of production, which in turn directly affects lead times and inventories. Therefore, lean manufacturers obtain a strategic advantage when competing with traditional mass producers for market share.

Some of the results of manufacturing companies that are applying Lean and Six Sigma principles are: obtaining and maintaining for many years superior returns on invested capital, trading stocks in the market at premium prices (in the case of publicly held firms), and increasing considerably their sales market share (George 2002). This is especially relevant if a company operates in a commodity industry sector, which is the case for many manufacturers.

1.3 Problem Statement

Anecdotal data affirms that companies applying lean or quality principles in order to improve their operations and processes not only deliver higher quality products, thus fulfilling the needs of their customer bases, but also obtain superior financial results as a direct consequence of applying these principles. The goal of this research is to empirically verify anecdotal data.

Therefore, the researcher proposes to analyze the financial characteristics of a group of publicly traded companies in the manufacturing sector with the intent of verifying if a correlation exists between companies applying lean and quality programs in their processes and superior returns on investments.

This research will mainly be a correlational study that will extract key Financial Performance Indicators (FPI) from annual financial reports from a large pool of publicly traded manufacturing companies. The main goal of this study is to show that financial benefits result from the systematic application of lean and quality tools.

This study will also verify that companies that have a business model that propitiates a high level of communication between them and their markets, because of the presence of lean and quality programs, will have a substantial financial advantage when compared to companies that still follow the traditional “mass production” business model.

1.3.1 Sub-problems

The first sub-problem addresses the question of whether or not lean and quality companies are able to communicate better and faster with their markets, attaining high levels of Information Velocity, and sustaining superior returns on their investments.

The second sub-problem is to determine whether there is a correlation between FPI levels and the application of lean and quality principles by publicly traded manufacturing companies. In other words, do FPI improve when companies have a Lean and a Six Sigma program in place?

1.4 Hypotheses and Justification

The first hypothesis states that companies that communicate faster and more effectively with their markets have high levels of Information Velocity, mainly because their lean business model allows them to do so.

The second hypothesis states that there is a strong correlation between FPI values and the application of lean and quality tools by manufacturing companies.

The final hypothesis affirms that lean companies do present superior levels of key FPI when compared to companies that do not appear to be lean, and that this superior performance can be proved to be statistically significant through a t-test.

1.5 Methodology

A mainly quantitative approach will be used in this research as a way to verify whether it is possible to identify lean companies by using Information Velocity theory, which was derived from Information Theory. Key FPI will be extracted from annual public reports of manufacturing firms available at the Security Exchange Commission (SEC) website. The SEC assigns 10-K reports for American companies to publish their financial results, and the corresponding report for foreign companies is the 20-F.

Various companies will be grouped within a business sector or industry and linear regression and t-test analyses will be used to draw conclusions. This project will use the research method of correlational study to achieve the research goals, identifying a possible correlation between the application of lean and quality programs and the improvement of financial operations. Some content and historical analyses might also be employed in this research with the intent to qualify which companies can be defined as lean and/or six sigma and which companies cannot.

The concept of Information Velocity, FPI, and the hypothesis that matched samples will reveal meaningful conclusions, including the other methods of research mentioned above, were all selected at the beginning of the research. The purpose of the chosen research methods is to objectively define the necessary variables capable to yield relevant results pertaining to this study. The researcher's final goal is to produce unbiased results demonstrating that the application of lean and quality principles help companies to attain financial outcomes superior to the market average.

Some of the variables or FPI to be extracted from annual reports are: Sales Revenue, Cost of Goods Sold (COGS), Total Inventory, Work-in-Progress (WIP) Inventory, Finished Goods Inventory, Inventory Turns, Current Liabilities, Accounts Payable, Pre-Tax Income, Income Tax, Market Capitalization, Return on Invested Capital (*ROIC*) and others. The variables were chosen with attention to their internal and external validity and reliability. The data collection in the form of variables is standardized, so that the researcher will be able to convert the information to numerical indices. The data will be collected from samples of public manufacturing companies to represent the universe of the worldwide manufacturing industry.

The Information Velocity concept and Information Theory were developed using an inductive approach by previous researchers, as stated above. This particular research, however, will employ a deductive approach to confirm the premises (hypotheses and the theory). The data will then be statistically analyzed to help the researcher objectively draw conclusions of the observed phenomena.

The precise reason why data will be statistically treated is to review possible correlations between FPI and lean companies. The data analysis might also be able to validate the competitive advantage of companies that employ lean strategies and quality programs. The conclusions of this study will eventually be generalized to all manufacturing companies: public and private, small and large, domestic and foreign.

1.6 Assumptions

The first assumption used in this research is that there is an increasing interest in the improvement of business management through the application of lean practices and quality tools.

The second assumption is that there is a direct application of Information Theory on business management through the concept of Information Velocity, or efficient communication. The researcher also assumes that the Information Theory and its derivative concept of Information Velocity is correct and has universal application.

The third assumption is that building and matching subgroups of certain publicly traded manufacturing companies that are competitors and representative of a focused business sector will allow the researcher to make valid comparisons using key FPI.

The fourth assumption is that key FPI are standardized across companies and can be easily extracted from annual reports, such as 10-K and 20-F, published at the Security Exchange Commission (SEC) website by manufacturing companies that trade their stocks in the U.S. markets.

The fifth assumption is that key FPI will continue to be used in the future to identify companies that apply lean and quality practices. This happens because the key FPI follow the guidelines of the Generally Accepted Accounting Principles (GAAP), thus revealing important information on how company operations are conducted.

The sixth assumption is that the selected publicly traded manufacturing companies used in this study are representative of the universe of all manufacturing companies in the worldwide industry, both public and private.

The seventh and last assumption is that each subgroup of companies representing a particular industry sector studied in this research is a homogeneous combination of traditional mass manufacturers, lean producers, and firms in the transitional process to become lean.

1.7 Delimitations

The study will be limited to analyze the annual financial reports published at the SEC in past five or ten years of thousands of publicly traded worldwide manufacturing companies. This restriction means that only companies that trade in the U.S. markets will be included in the study. Furthermore, most of the data will be extracted from the Wharton Research Data Services (WRDS) using the COMPUSTAT North America database. Some of the data could also come directly from the SEC website, at www.sec.gov/edgar.shtml, or from the Reuters website, at www.reuters.com.

The researcher will initially divide these companies into subgroups of two competitors of a particular industry sector, one competitor being well-known in the press as an early adopter of lean or quality practices and the other being well-known as a non-adopter. Other possible combinations of company categories might appear later on in this study according to the need to show points of interest in this research.

This study will only use U.S. currency. Whenever a foreign company publishes annual reports using foreign money, the amounts will be converted into U.S. dollars using a retroactive rate of conversion according to the publishing date. One possible exception to this delimitation is when the original currency is used to provide key FPI ratios, since ratios will always be the same regardless of currency. Generally speaking numbers used on this study will appear in millions of dollars, unless otherwise indicated.

Finally, this study will NOT attempt to predict the future success of manufacturing companies that apply in their operations either lean initiatives, quality programs, or a combination of the two.

1.8 Thesis Contribution

The Toyota Production System (TPS) and its Just-In-Time or lean production method has been one of the greatest success stories in the history of manufacturing. The TPS provides the framework for companies trying to cut down costs and improve their value-adding activities. Since Toyota started applying lean strategies, several other companies have tried to do the same, successfully implementing lean concepts, quality tools, or a combination of the two, being able to remarkably improve their financial position in the market.

Companies that have been applying these tools and strategies testify of a strong financial progress and a high customer appraisal because of exceeding quality of their products and services. The relevance of this study is to validate such statements of success. If the hypotheses of this research are proven to be true, it will eventually serve as an incentive to other businesses to decide that they also should apply the same tools and strategies to achieve similar results.

The key strategic insights of this study are particularly relevant to senior managers, because it will inform them how to get ahead and stay ahead of their competitors by improving their company's Information Velocity or the way they respond to the market demand. Finally, this study might indicate that process improvement is a safer investment and has bigger returns than the traditional investments on pioneering innovation through continuing development of new products.

1.9 Glossary

- Blackbelts: Improvement specialists that apply Lean and Six Sigma methodologies to specific projects. They usually devote 100% of their time solely to execute improvement projects.
- Dynamism: Indicates the level of environmental volatility in a particular industry sector. In the case of demand volatility, it relates to sales revenues over time.
- Commodity: Products having equivalent value and uniform quality provided in large quantities by many different producers.

- Continuous Flow: A manufacturing strategy which the primary goal is an optimally balanced production line with no waste and having the lowest possible cost, with on-time deliveries and defect-free production.

- Entropy: The level of disorganization in terms of information possibilities. It measures the average uncertainty or choice as to what a source will produce next. The units are bits per choice or bits per second.

- Financial Performance Indicators (FPI): A set of financial variables and ratios extracted from annual reports of public companies, such as balance sheets and income statements. These indicators include: annual sales, inventories (work-in-progress, finished goods, and total inventory), inventory turns, ROIC, market capitalization, etc.

- Information Theory: A discipline in applied mathematics involving the quantification of information with the goal of reliably communicating as much data as possible over a particular channel.

- Information Velocity (IV): How fast a producer can decipher and fulfill (create and deliver) the market demand for products. It is quantified by the ratio of useful information transmitted by the market divided by the necessary time required by a producer to respond to that demand. A High level of IV is a necessary and sufficient condition for achieving and maintaining Supernormal Returns on investments.

- Inventory: A part of the product that is not immediately required for a customer order, such as raw material, work-in-progress, and finished goods.

- Inventory Turns/Turnover: The ratio of annual sales to inventory that is turned over in a period of one year. In this work, Inventory Turns often appears as Cost of Goods Sold (COGS) divided by Total Inventory.

- Invested Capital: Represents the total investment that shareholders and debtholders have made in a company. It is calculated by subtracting cash, short term investments and total current liability from total assets.

- Just-in-Time (JIT): The manufacturing and conveyance of producing only what is needed, when it is needed, and in the amount needed. It is built upon three basic principles: Pull System, Continuous Flow, and Takt Time.

- Lean Manufacturing/Production: A management philosophy focused on the reduction of the eight wastes: transportation, inventory, motion, waiting time, overproduction, overprocessing, defects, and lack of creativity.

- Lean Six Sigma: A business improvement framework that integrates Six Sigma methodology with the cost reduction benefits of Lean production.

- Market Capitalization: A measurement of corporate size that refers to the current stock price times the number of outstanding shares. It may not reflect accurately the intrinsic company value because it depends on future expectation held by investors.

- NOPAT (Net Operating Profits After Taxes): A company's after-tax operating profit, or net income after tax.

- Pull System: Where materials are moved from one operation to the next based on a request from the next operation.

- Push System: Where materials are automatically moved from one operation to the next, whether or not they are needed.

- ROIC (Return on Invested Capital): A financial measure that quantifies how well a company generates cash flow relative to the capital it has invested in its business. In order to create value, a firm must earn an ROIC that is higher than its Weighted Average Cost of Capital (WACC). ROIC is calculated by dividing its NOPAT by Invested Capital.

- Scientific Management: The approach to management, industrial engineering and organizational psychology concerning labor organization, initiated by Taylor in 1911.

- Six Sigma: A business improvement methodology focused on the systematical process of eliminating defects. It was originally defined as a quality program that reduces defect levels below 3.4 parts per million, or controls a process to the point of plus or minus six standard deviations (sigma) from the centerline.

- Statistical Process Control (SPC): A set of methods using statistical tools, such as mean, variance, etc., to detect whether a process observed is under control.

- Supernormal Returns (SNR) or Economic Profit: A superior return on invested capital that is greater than returns earned on investments of equivalent risk. In other words, it is an abnormal superior profit over a normal opportunity cost of doing business.

- Takt Time: German word for rhythm. It is the total available work time per shift divided by customer demand requirements per shift. It sets the pace of production to match the rate of customer demand.

- Theory of Constraints (TOC): An overall management philosophy that aims to continually achieve goals set in a production system environment. This is accomplished by exploiting the system's bottlenecks and constraints and by optimizing its capacity.

- Total Quality Management (TQM): A management approach centered on quality. It is based on the participation of all associates and it aims at long-term success through customer satisfaction and the resulting benefits to labor and society.

- Toyota Production System (TPS): A philosophy of organizing manufacturing and logistics at Toyota that includes the interaction of suppliers and customers. It is heavily based on, but not limited to lean and quality improvement programs.

- Value Creation: To provide all features of a product or service for which customers are willing to pay.

- Waste: Any activity that takes time, resources, or space, but does not add value to a product or service.

2 Literature Review

2.1 Introduction

This research initiated with an extensive literature review on topics such as operations management, manufacturing process improvement, communication, and other materials related to strategy and technological innovation. The foundation to clearly understand the scope of the project was laid by articles and books focused on lean and six sigma programs. The next step undertaken was an analysis of the mathematical principles that govern efficient communication – Information Theory. The business application of Information Theory through the concept of Information Velocity (IV) was then carefully examined. Other materials related to Information Theory were also analyzed as supporting literature. A variety of other articles and books indirectly related to the project, such as scientific management, operations management, and managerial accounting was also reviewed in order to enlarge the researcher's understanding of operations. Concluding, a summary of two studies comparing the financial results of lean companies against traditional mass manufacturers was examined. A brief description of the materials used in the literature review is presented below:

2.1.1 Lean Six Sigma

Many authors have published materials on systems improvement, focusing either on lean production or quality. Some of these researchers include: James P. Womack, Daniel T. Jones, Jeffrey K. Liker, Taiichi Ohno, Henry R. Neave, and Shigeo Shingo. However, only a few authors have written about the integration of six sigma methodology with the cost reduction of lean production. Because Michael L. George published extensively on the integration of both Lean and Six Sigma, he is one of the authors often quoted in this research.

2.1.2 Information Theory

In 1948, the American mathematician Claude Shannon published an important article in the *Bell Systems Technical Journal* concerning the quantification of data with the goal of reliably communicating as much information as possible over a channel. Shannon's paper was developed during WWII while he was working for Bell Labs looking for ways to improve the transmission of intelligence between the Allies and deciphering the enemy's communication. This paper became the foundation of a discipline in applied mathematics known as Information Theory.

Information Theory turned out to have many practical applications. It was crucial for space communication, invention of compacted disks, development of the Internet, study of linguistics, music, and human perception. John Pierce, another Bell Labs associate, popularized some of the applications of Information Theory while working under the direction of Shannon. Researchers like Michael L. George and Robert B. Johnston, professor at the University of Melbourne, recently published several articles on the applications of Information Theory in business improvement and operations management.

2.1.3 Supporting Theories

Other authors have also published many books and articles on business improvement and strategic planning, aiming to achieve and maintain higher returns on investments through good management practices, product development strategies and innovation. Clayton M. Christensen, professor at Harvard Business School, pointed out the importance of disruptive technologies that comes through innovative products. James C. Collins, former professor at Stanford Business School, described how companies transition from being average businesses into great visionary corporations.

The theories above were chosen as part of the literature review because they are related and because they support each other. A more deep analysis of the primary ideas of process improvement applicable to this research is given in the following sections.

2.2 Speed and Quality Are Linked

One of the first process improvement programs widely used in industry was Statistical Process Control (SPC), which mainly focused on controlling quality. SPC was pioneered in the 1950s in Japan by statisticians Shewhart, Deming and Taguchi. Around the same time SPC evolved into a more complete quality program, Total Quality Management (TQM), which was mainly developed by Juran and Ishikawa. TQM addressed quality issues from a management perspective. These programs had a tremendous impact on quality and process improvement, and they became the precursors of the Toyota Production System (TPS) developed by Ohno, Shingo and others. A few years later, Six Sigma was developed by Galvin and Smith at Motorola.

In the 1980s, there was a great pressure on the worldwide manufacturing industry to improve quality and speed of production. The leading companies in the market had critical quality tools already in place, such as value stream mapping, data collection, analysis of variance, setup time reduction, design of experiments, etc., all reminiscent from the pioneering quality programs. These tools formed a vital foundation to the development of both Lean and Six Sigma.

Ever since the quality movement started, many prominent companies concentrated their efforts on either Six Sigma or Lean, but usually not on a synergic combination of the two. The reason why so many companies selected just one of the two programs is because they believed that all quality improvement programs were somewhat alike. Their general perception was that all of these programs might be able to achieve similar results at the end of the day. The trouble with this type of reasoning is that the application of a single program only addresses part of the operations problem, thus only partially improving finances.

For instance, Six Sigma might help a company reduce the defect rate of a process to near zero (six sigma quality or three defects per million parts), thus reducing approximately 50% of the non-value-adding-costs associated with production. And Lean production might be able to reduce the production lead times from several weeks down to a few days, thus reducing the other 50% of non-value-adding-costs. Therefore, if a company combines both programs, it is in the position to achieve greater results because it approaches production from two fronts, quality and flexibility. The combination of quality and speed eventually can build momentum to reduce up to 90% of non-value-adding-costs (George 2003).

Some of the accomplishments that Lean and Six Sigma programs combined can do are the following: dramatically improve the bottom line and shareholder value, eliminate large quantities of waste, reduce costs and production lead times, improve resource utilization, machine cycle times and production flexibility. Improvements can be verified after a period of time and might be measured by key Financial Performance Indicators (FPI) published in annual financial reports. As discussed previously, not all the relevant financial information on operations of publicly traded companies are required to be disclosed in annual reports by the Security Exchange Commission (SEC). However, the existing indicators might very well serve to demonstrate if companies apply lean and/or quality principles to their operations, in order to reap the financial results.

2.3 Mathematical Approach

The literature based on process improvement extensively discusses how companies can reap the financial benefits of a consistent application of lean principles and quality tools. What is interesting to note is that not very many key people in industry have awareness of the mathematical principles governing these strategies behind the scenes.

In the beginning of this chapter the article formulating Information Theory, published by Claude Shannon in 1948, was briefly introduced. The theory explains the transmission of information in the form of binary digits, and it is widely used today in the fields of computer science and digital communication. It basically states that information transmitted over a channel by a random source has a certain probability of occurrence (Shannon 1964 1949). In other words, there is a certain uncertainty with respect to the message that a source produces.

For instance, if I know what an individual will say before she says it, what she says can convey no information to me. Shannon called the uncertainty with respect to the message, Information Entropy. Entropy is a valid quantitative measure of information transmitted, because it measures the level of disorganization of any message in terms of information possibilities. The degree to which messages from a source are unpredictable is taken as a measure of the amount of information contained in such messages. It is important to understand that entropy is a characteristic of the source that produces a message, and not of an individual message.

Therefore, Information Theory does not tell us about the generation of a particular message and its transmission over a communication channel at a particular time, rather it tells us about the average behavior of a message source. This interesting concept explains why Information Theory has a probabilistic or statistical nature (Pierce 1965 1961).

Consider the outcome of successive tosses of a coin as messages from a given source. When we toss an unbiased coin, heads or tails comes up with equal probability of 50% each. The outcome of a particular toss is not influenced by the outcome of previous tosses. Shannon took the uncertainty of outcome of any equally likely possibility as his fundamental measure of entropy, or amount of information transmitted. The unit of information has come to be called the *bit* (binary digit).

The amount of information that a source produces depends both on how many different messages or outcomes the source can generate, and on how uncertain we are concerning which message the source will actually produce. If the source is able to produce only one message, it generates zero information per message. If it generates any number of *n* messages with equal probabilities, then the amount of information or its counterpart entropy is given by the logarithmic function of base 2:

$$H = \log_2 n \tag{2.1}$$

The successive tosses of an unbiased coin convene a message from an information source at the rate of 1 bit per message, or $\log_2 2$, because the toss of a coin can only produce two messages: heads or tails. However, the throw of an honest dice (another information source) produces more information than the toss of a coin, because any of the six numbers can come up. Therefore, the information or entropy per throw of a dice is $\log_2 6$, or 2.58 bits per throw (Pierce 1990).

The application of Information Theory in business is based on the idea that a market can be considered a stochastic transmitter, mainly because it has a highly unpredictable nature. A company in a particular business sector, such as an auto manufacturer for example, is a receiver of this highly uncertain and random information that was transmitted, which is in this case the demand for cars. (See **Figure 2.1**)

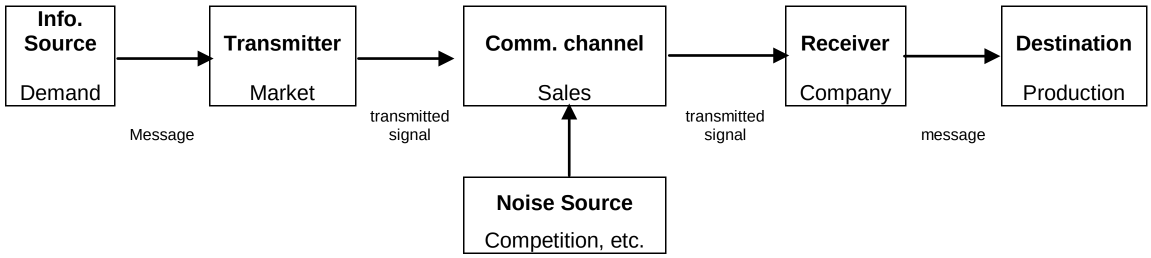

Figure 2.1 – Information Flow

If a company can anticipate the market demand for a period of time, a month for example, it will be able to respond better to the customer needs on that particular month, producing only what the market wants, when it wants. According to Shannon, such an efficient communication would lower the level of Information Entropy, thus reducing the surprise element of communication (Shannon 1964 1949). This phenomenon happens because the receptor (auto manufacturer) is able to either predict the message (demand for cars) or respond to it faster than competitors.

Let us consider a specific example of internal process entropy from the auto manufacturing industry. For simplicity purposes we will regard the message transmitted by the market, the demand for cars, as a choice between two outcomes: car A (sedan) or car B (SUV). There are only two manufacturers competing for this market: one is a lean company and the other is a non-lean (mass) company. Therefore, one produces in small batches, like Toyota, and the other in large batches, like General Motors (GM). Let us keep in mind that none of the manufactures know before hand what the market demand is, for this reason the message transmitted is uncertain. In the period of time of one month the market will randomly demand the production of nine sedans (car A) and seven SUVs (car B), in the following order:

Demand: BAAABAABBBABABAA = 16 bits per month.

Suppose that GM (mass producer) has a high changeover cost, it consequently produces cars in batches of 8 WIP inventory to amortize costs, thus having only two changeovers during the month, one at the beginning of production and the other in the middle of the month.

GM supply: BBBBBBBBAAAAAAAA = 2 bits per month.

The process entropy is calculated as $\log_2$ (WIP), since the number of WIP represents the possibility of choices for production. Consequently, the entropy of production for GM is $\log_2 8$ (eight WIP inventory in each batch), or 3 bits per month. Because supply does not closely match demand, GM creates waste in the form of non-value-adding costs. These costs are driven by inventory warehouses, scheduling, scrap, rework, and obsolete products. We can see this waste reflected by the high entropy of production, in this case 3 bits per month.

Because Toyota (lean manufacturer) has changeover costs near zero, it usually produces only what the market demands. In consequence, Toyota will have batches with the minimum amount of WIP (ideally 1 piece of inventory per batch) and as many changeover as necessary.

Toyota supply: BAAABAABBBABABAA = 16 bits per month.

The entropy of production of Toyota is $\log_2 1$, or near zero bits per month. Because supply closely matches demand in the case of Toyota, it incurs the lowest possible non-value-adding costs. Toyota's flexible and effective production is reflected by the very low entropy of production, in this case near zero bits per month.

The ability of a company to communicate effectively with its market in order to reduce waste can more easily be achieved when lean and quality programs are in place. The next sections will show some of the financial benefits for a firm that closely matches its supply with the market demand, thus becoming a more flexible producer. Note that Johnston published extensively on this subject and his works are referenced in the bibliography section (Johnston 1997).

2.4 Information Velocity and Financial Operation

Michael L. George defines Information Velocity (IV) as the ability to respond correctly to highly uncertain market demands. A manufacturing company that transforms information into offerings faster than what customers expect and faster than competitors do is operating at breakthrough IV. The ability to respond fast enough to the market demand removes Information Entropy out of the communication process, thus increasing the level of productivity and IV. When a firm operates at high levels of IV, it is exchanging information with the market at high speeds. This efficient communication results in eliminating large amounts of costs, attaining large quanta of revenue growth, and receiving a premium from the market in the form of Supernormal Returns (George 2006).

George also affirms that companies that achieve better Returns on Investments, do so because they focus more on process improvement and complexity reduction (through the acceleration of lead time of internal processes), than they do on pioneering innovation (through the creation of new products). An exception to this rule of thumb happens when legal monopolies are established in consequence of disruptive technologies, especially when these technologies are appropriately secured by patents (George 2006).

The IV equation is mathematically derived from Little's Law, which states that the average completion rate of a process is the ratio of the number of items being processed divided by the lead time necessary to process these items. Thus, IV can be simply defined as the ratio of useful information received from the market divided by the necessary lead time to deliver those offers that satisfy demand:

$$Info\,Velocity\,(IV) = \frac{Info\ per\ Event}{Lead\ Time} \tag{2.2}$$

An interesting relationship between IV and entropy exists. According to Shannon's theory, information is negative entropy. And when IV is accelerated because information is added into the system, entropy is consequently reduced. This phenomenon is analogous to the behavior of an internal combustion engine. Boltzmann's equation explains that when entropy increases inside of an engine (system), so does internal waste; consequently the engine's capacity to realize work is lowered. However, when the level of entropy (disorganization) is reduced inside of an engine, the engine becomes a more efficient machine (Fermi [1956 1936]).

How can the internal process entropy of a manufacturing system be reduced or eliminated? It can be accomplished by adding information into the system via process improvement, complexity reduction, and careful development of new products (George and Wilson 2004) and (George 2005). Process improvement injects information into processes by reducing setup time, defect rates, processing time, lead time, WIP, and manufacturing overhead costs. Complexity reduction contributes to speed up IV by reducing the number of components (elements) of a part, and consequently the number of tasks necessary to deliver the final product. Product development also helps to increase the flow of information. Successful product innovation usually occurs either by reverse engineering (manufacturing similar products already marketed), or by pioneering disruptive technologies (George 2006) and (Christensen 1997).

Process improvement and complexity reduction affect the IV equation by reducing the denominator; whereas, product creation affects the equation by increasing the numerator. Increasing the numerator of the IV equation only accelerates the information flow linearly. The numerator can be regulated by the number of new products which create economic profit, or Supernormal Returns. This means that Return on Invested Capital (*ROIC*) on those products is greater than the opportunity cost of investing capital somewhere else. Now, information flow can be exponentially accelerated by reducing the denominator (process lead time) in the IV equation.

Therefore, it is easier and more powerful to accelerate IV by manipulating the denominator (through process improvement and complexity reduction) than by increasing the numerator (through product innovation). Besides, the fact that process improvement carries less risk and is usually more successful than product development is well accepted in industry.

Let us analyze another example that shows why lean and setup reduction, the heart of Toyota Production System, accelerates the exchange of information between producers and their markets (George 2006). Suppose a company offers 10 different products, “0” through “9”, and assume that this firm is capable to produce after setup time 1,000 parts per hour of any of the 10 products. For production to be cost effective, the plant manager will desire to run large batches in order to amortize setup cost, which in this case can take up to 2 hours. Each large batch takes an average of 14 hours to be finished. It will eventually take this company four weeks (40 working hours each week) or 160 hours to deliver the 10 products, totaling 140,000 parts. (See **Figure 2.2**)

Setup (2hr)   Batch Run (14hr)
____0000000000____1111111111____2222222222____…→…____9999999999
←————————————— 160 hours ———————————————→

Figure 2.2 – Mass manufacturing

It would be perfect if customers could just sit around and wait four weeks until production is completed. The problem here is that customers will only accept products delivered one week after the order was placed. Therefore, the company must reduce the batch size and learn how to changeover faster from one product to another.

In the new scenario each batch should take a maximum of 3.5 hours to be manufactured and the setup time must be reduced to less than 30 minutes. Working under these lean conditions, the company is able to deliver the 10 products, totaling 35,000 parts, in about one week. (See **Figure 2.3**)

Setup (.5hr)   Batch Run (3.5hr)
_000_111_222_333_444_555_666_777_888_999
←——————— 40 hours ———————→

Figure 2.3 – Lean manufacturing

From an information perspective, manufacturing these 10 products conveyed $H_{10} = \log_2 10$, or 3.32 bits of information per product. However, mass manufacturing or producing in large batches (14,000 parts each) only conveyed $H_{10} = (\log_2 10)/160$, or 0.0208 bits of information per hour. Lean manufacturing, or producing in small batches (3,500 parts each) and using shorter setup times, conveyed $H_{10} = (\log_2 10)/40$, or 0.0830 bits of information per hour. Note that the entropy equation was divided by lead times.

As a result, lean manufacturing generated information four times faster than mass manufacturing. Adding information into the process by employing setup time reduction and the use of smaller batches increased the channel's carrier frequency while holding the use of bits per channel constant at $\log_2 10$. Lean practices increased the rate of information transmission (bit rate) four fold, which translates into a considerable increase of speed of information in the IV equation!

Higher levels of IV can only be achieved when the transmission of information from supply is closely matched by the flow of information originating from demand. In reality, this can be achieved by simultaneously applying lean and quality principles, because both practices inject flow of information into the process.

The ability to respond better and faster to customers helps companies in several ways: reducing the amount of capital employed in inventory, avoiding the risks of amassing obsolete finished goods that might never be sold, and reducing the physical space required to store inventory. Reducing the level of inventory further reduces manufacturing overhead costs and allows production personnel to improve quality by catching mistakes right away because of the ability to manufacture goods in a single-piece-flow fashion. Other natural consequences are an increased throughput, quality, and other positive results that are not easily quantifiable, e.g. employee workmanship. These and many other beneficial results of having a high level of IV, which in Information Theory translates to a lower market and production entropy, ultimately reflect in cost reduction, margin enhancement, revenue growth, and competitive advantage. High IV allows companies to increase *ROIC*, which ultimately is what shareholders value.

As defined before, *ROIC* is intuitively an indicator of the ability a firm has to create value. For instance, a publicly traded company that creates value at a level of 10% superior to the cost of investing such capital might eventually be able to trade its stocks in the market up to ten times the book value. To reach and maintain this competitive advantage of economic profit is defined by George as Supernormal Return (George 2006).

2.5 Lean Six Sigma Value Proposition

The book *Lean Six Sigma* includes some specific examples of financial benefits seen by companies focusing on process improvement. The example below shows a progress made by a tier-one auto supplier that thoroughly applied both Lean and Six Sigma methods during 26 months to improve company value for shareholders. The benefits harvested by United Technologies Automotive Hose and Fittings are summarized below:

- Operating Margin: from 5.4% to 13.8%
- Capital Turnover: from 2.8 to 3.7
- ROIC: from 10% to 33%
- EVA = ROIC%-WACC%: from -2% to 23%

• Enterprise Value ($Million)	from 64	to	208
• Revenue ($Million)	from 144	to	311
• EBITDA:	increased		300%
• Manufacturing Lead Time:	from 14 days	to	2 days
• WIP Inventory Turns:	from 23	to	67 turns per year
• On-Time Delivery:	from 80%	to	>99.7%
• Quality Performance:	from 3σ	to	6σ

These goals are attainable when process improvement is implemented and supported by the CEO and the company leadership. Blackbelts and other key managers should also be part of Lean Six Sigma teams to ensure that the improvement projects will be successfully completed. The full details of how to implement process improvement programs are outside the scope of this work. A further understanding of how to implement Lean Six Sigma can be found in various works, including the book *Lean Six Sigma*, under the section "The Lean Six Sigma Implementation Process" (George 2002).

2.6 Innovation and Management Excellence

As mentioned previously in this chapter, shareholder value can be rapidly grown either by process improvement or by disruptive technologies properly protected by patents. At one hand, Clayton M. Christensen described in the book *The Innovator's Dilemma* how disruptive innovation eventually can overturn the existing dominant technology or products in their own markets, and still yield higher returns (Christensen 1997).

Disruptive innovation is a paradigm shift that can be broadly classified into two categories, lower-end disruption and new-market disruption. Christensen distinguishes between low-end disruption, which targets customers who do not need the full performance valued by customers at the high-end of the market, and new-market disruption, which targets customers who previously could not be served with profit by incumbent companies. Consequently, new-market innovations are often aimed at non-consumption customers, whereas, lower-end innovations are aimed at mainstream customers who had been previously ignored by established firms.

Sometimes, a disruptive technology comes to dominate an existing market by either filling a role in a new market that the older technology could not fill (as more expensive, lower capacity, but smaller-sized hard disks did for newly developed notebook computers in the 1980s) or by successively moving up-market through performance improvements until finally displacing the market incumbents (as digital photography has begun to replace film photography).

An important low-end disruption phenomenon happened when PCs started to substitute minicomputers and workstations. When PCs originally came, they were very simple and less expensive machines compared to workstations. Because workstations were designed to satisfy the demand of high-end users, they were expensive and technologically mature. PCs eventually were able to evolve and to substitute most of the minicomputers and workstations. This example shows that oftentimes mature technology and high-end products outperform the average customer expectation, consequently not fulfilling more generic customer needs.

New market disruption occurs when a product that is inferior by most measures of performance fits a new or emerging market segment. For example, when the operating system Linux was first introduced, it was considered being inferior in performance when compared to other operating systems for servers, such as Windows. After years of improvements on this open-source and easily available operating system, the Linux functions have improved so much that it now threatens to displace the leading operating systems.

Many companies that became market leaders can be considered at least one-time disruptors. A few, including IBM, Intel, Microsoft, HP, Johnson & Johnson, Kodak, and Cisco, have developed disruptive technologies many times. Sony did it repeatedly with much success between the years 1955 and 1982 (Christensen 2003).

Christensen, in his first book on disruptive technology, explains how disruptive innovative technologies are eventually hidden from the industry leaders, precisely because they focus too closely on the needs of their most profitable customers and businesses. In his second book, *The Innovator's Solution*, Christensen shows how companies can overcome this dilemma by creating disruptions rather than being displaced by them.

At the other hand, Jim Collins focuses on leadership and management to improve the company's value. In his book *Good to Great*, Collins identified and evaluated the factors and variables that allow a small fraction of companies to make the leap from being merely good firms to become truly great companies (Collins 2001). Great companies are defined by Collins according to a number of metrics, such as, financial performance that exceeds the market average by many times over a sustained period of time. Or in other words, companies that created and sustained Supernormal Returns.

Collins' main argument is the need to define a narrowly focused objective and field of competency and then employ all of the company's resources toward that area of strength. Losing perspective and getting astray from a company's established strengths is counterproductive to the attainment of greatness, according to Collins.

In his previous book, *Build to Last*, Collins outlined the results of a six-year research project of what makes enduring great companies (Collins 1994). Collins identified underlying characteristics that are common to highly visionary companies. These are premier institutions in their industries. They are widely admired by knowledgeable people, and they have made an indelible imprint in the world. These companies usually had multiple generations of CEOs, had multiple product/service life cycles, and were founded before the 1950s.

Many of these companies ended up becoming the standard in their industries, not only because they continuously offered innovative products and services, but also because they consistently outsmarted their rivals. In both books, Collins compared and contrasted these great visionary companies with a control set of rivals. For instance, Marriott was compared and contrasted with Howard Johnson, Merck was compared and contrasted with Pfizer, and Wells Fargo was contrasted with Bank of America.

The findings of both books are based on management practices used by the great and visionary companies; practices that are different than the ones used by close competitors who have achieved a high level of success, but not to the extent of the great ones. Again, because of good and simple management practices employed continuously over time these great and visionary companies consistently outperformed many times the general stock market.

2.7 Other Studies Analyzing the Effects of Lean on Finances

Claycomb published an article at the *International Journal of Physical Distribution and Logistics Management* arguing that the implementation of JIT can improve business performance. This article provided evidence that companies that have substantially cut lead times, drastically reduced raw materials, work-in-progress, and finished goods inventory, thus effectively increasing their asset turnover, Return on Investment (ROI), profitability, and Return on Sales (Claycomb and Germain 1999, 612).

These financial metrics are all closely related to *ROIC*. The findings of this particular study provided empirical evidence that companies that employed JIT strategies, or lean manufacturing, for over three years, were able to produce improved financial performance and competitiveness when compared with companies that did not employed such initiatives (Claycomb and Germain 1999, 612).

Another research published in *The Accounting Review* journal in 2002 dealt with some of the evidences of JIT's profitability effects. Kinney and Wempe used a large sample of JIT adopters and matched non-adopters to examine the associations between JIT adoption and financial performance. They found that JIT adopters outperformed matched firms in profit margin and asset turnover, both components of return on assets (ROA), also over a three-year post-adoption period. The ROA changes for JIT adopters exceeded the changes of non-adopters by a highly significant difference. They also found that relative ROA improvement is concentrated among the earliest JIT adopters, especially among larger firms, which may have the most to gain from the JIT adoption (Kinney and Wempe 2002, 203).

These results clearly suggest that a “first mover” advantage existed for early adopters, followed by dissipation of the advantage as JIT becomes more widely adopted. They also suggest that JIT, or lean manufacturing, made the production setting more transparent, thus assisting line workers and management alike in realizing cost-savings because of process improvements (Kinney and Wempe 2002, 203).

In conclusion, both research studies are strong evidence that companies adopting a Lean Six Sigma strategy are prone to receive higher returns from their investments.

2.8 Summary

The literature revealed that many steps are necessary to create really great and visionary institutions – innovative businesses and market leaders. These companies can be recognized by the excellence of their products and services. They are capable of sustaining growth, outperforming the general market, and yielding superior returns.

This research emphasized process improvement among the many things that companies can do to improve their finances. Counter to conventional wisdom, capital investment in improvement programs, such as lean manufacturing and quality control, is a safer investment and it yields superior returns than exclusive pioneering innovation (research and development of newer products). An exception to this rule might be when disruptive technologies arise protected by patents.

The superiority of process improvement strategies is explained by Information Theory and by the IV equation: companies respond better and faster to complex market demands and become more flexible producers because they exchange information with the market faster than competitors.

3 Methodology

3.1 Introduction

This chapter begins with a discussion and description of the Information Velocity variables chosen as indicators of lean and quality attributes (FPI). The following sections present an interesting historical overview of Ford and General Motors, the two major worldwide auto manufacturers in the past 50 years, and a case study comparing and contrasting the operations and financial results of the two largest computer manufacturers in the U.S is introduced (Dell and HP). Both studies, the case comparing Dell and HP and the overview of the auto industry, are particularly relevant for this research because they point out why lean companies can succeed financially over mass manufacturers, especially when these firms are found in a competitive environment. It also demonstrates that lean companies obtain cost leadership by maintaining a high level of information velocity in their systems. Finally, the chapter concludes with a section explaining the data collection process for this research study.

3.2 Information Velocity Quantifiers

A series of variables capable to quantify IV were proposed in the literature, especially by George and Johnston. Some of the suggested variables were: product portfolio, lead time, WIP, finished-goods, inventory level, quality, Return on Invested Capital (*ROIC*), statistics on labor injury, worker's compensation, etc. (George 2002). Ideally all the variables mentioned above would have to be included in this study to support the hypotheses. However, not all variables are widely available to researchers. Unless one has inside knowledge of a company's financial data, the only type of information publicly available is the annual financial report. The reason for great secrecy is because companies want to safeguard their financial performance and other sensitive data from competitors, thus only disclosing data that it is required by law.

The other problem faced by many researches trying to extract data from financial reports is that the Generally Accepted Accounting Principles (GAAP), the standard framework of financial accounting in U.S. and most of the world, are primarily based on traditional accounting metrics. And at times these old metrics are not the best instrument to account for all cost drivers present in modern production systems.

Therefore, this research study narrowed its scope to only analyze publicly traded manufacturing companies having sales revenues above $2 billion a year. There are three reasons for these constraints. First, it is more intuitive to quantify IV for companies making products than it is to quantify IV for service companies, even though it is not impossible to do so for the service industry. Second, public companies trading their stocks in U.S. markets are required by the government to provide financial information to the shareholders and the general public. This type of information is published in annual reports such as 10-K (for domestic companies) and 20-F (for foreign companies), and can be found online at the Security Exchange Commission website (Security Exchange Commission 2007). Third, companies having a high volume of sales are more likely to have in a place a mature Lean Six Sigma program, thus facilitating the measurement between lean companies and mass manufacturers. Once all factors considered above are combined, the choice of variables that can be used to measure lean production and financial performance is the following:

Production Indicators:

1. Inventory-to-Sales Ratio (Inv/Sales)
2. Inventory Turns
3. Cost of Goods Sold
4. Sales Revenue

Financial Indicators:

1. ROIC
2. Net Operating Profit After Taxes (NOPAT)
3. Total Assets
4. Cash
5. Current Liability

The production indicators are assumed to be the drivers of financial results. For this reason *Inv/Sales* and *Inventory Turns* were assigned to be independent variables and *ROIC* to be a dependant variable. See below how to calculate each of the variables:

$$Inv\,/\,Sales = \frac{Total\ \ Inventory}{Total\ \ Sales} \qquad \textbf{(3.1)}$$

$$Inventory\ Turns = \frac{Cost\ of\ \ Goods\ Sold}{Total\ \ Inventory} \qquad \textbf{(3.2)}$$

$$ROIC = \frac{NOPAT\ (pretax\ income - income\ tax)}{Total\ \ Assets - (Current\ \ Liability + Cash)} \quad \textbf{(3.3)}$$

The goal of this study is to find any possible correlation between the levels of inventory, a widely acceptable measure of how lean a firm is, and *ROIC*. According to George, *ROIC* probably is the best financial indicator of "leanness" because it can show readily if management is using the company's resources to create value.

The initial research experiments will comprise of a set of linear regressions using data from a group of manufacturing companies competing in the same industry. One of the competitors will supposedly be known in the press as an early adopter of quality improvement, lean manufacturing, or a combination of the two programs. The other competitor will be a company that still conducts its operation business in a "mass" style. Thus, producing according to schedule, in large batches, and exploiting the economies of scale. Matching these two groups of firms will allow the researcher to make valid comparisons using the above cited variables.

The first objective of the research study will be to find a correlation between low inventory levels and high levels of returns on invested capital. At one hand, if *Inv/Sales* is chosen to be the independent variable, the resulting model will present a negative correlation with *ROIC*. At the other hand, if *Inventory Turns* is chosen instead of *Inv/Sales* to be the independent variable, then the model will generate a positive correlation with *ROIC*. And this makes sense because the hypothesis of this work states that lower inventory levels produce higher returns on investment, while higher inventory turnovers are rewarded by superior returns.

In the case that the initial linear regression experiments with matched-pairs do not yield a strong correlation, then a t-test study will be performed. The goal of the t-test experiment is to understand how higher supposedly the *ROIC* would be for lean companies. The t-test experiments might also elucidate if the group of lean companies can be considered, statistically speaking, different from the group of mass manufacturers, i.e. to pass the test of randomness and bias.

3.3 A Brief Overview of the Automobile Industry in the Past 50 Years

Let us now try to understand why at around 1970s many American companies decided they should start cutting costs, streamline their productions, and become more efficient and lean. As mentioned in **Chapter One**, after WWII the Japanese had to cope with a terrible economic crisis and deficiency of raw-materials to rebuild a country torn by war. Initially the Japanese and later the Europeans became very good at managing limited resources, while at the same time increasing their market share. After a few decades of intense efforts, these foreign companies initiated to pose a threat to American companies, right inside of the U.S. market. The stiffer competition from foreign businesses forced the American industry to adopt similar management tactics (quality and lean management) in order to survive.

The figures below show financial data for Ford and for General Motors trailing the past 50 years. Note how *ROIC* have been steadily declining over the years. (See **Figures 3.1** and **3.2**) The downward pressure on *ROIC* was probably due to fierce competition coming from Toyota Motors and other European automobile manufacturers, and due to government deregulations and subsequent market fragmentation. Customers started to require superior quality on products, and would not accept anything less than competitive prices.

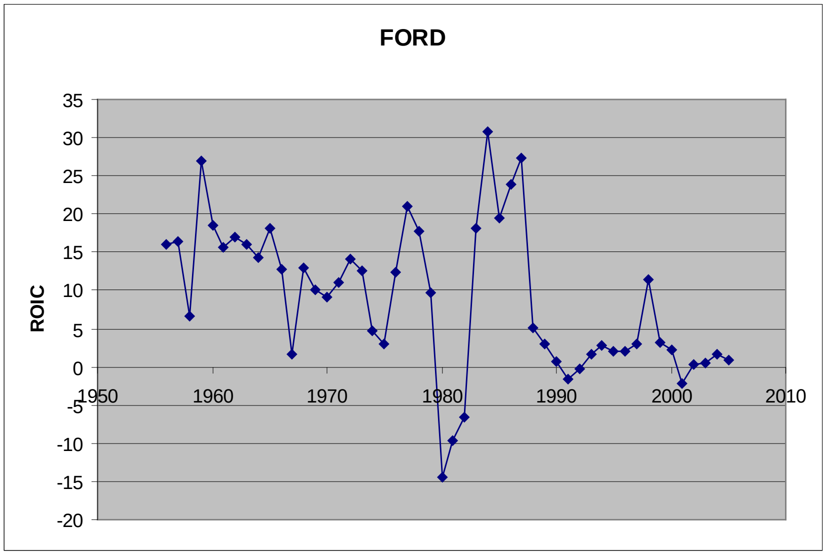

Figure 3.1 – Ford's ROIC

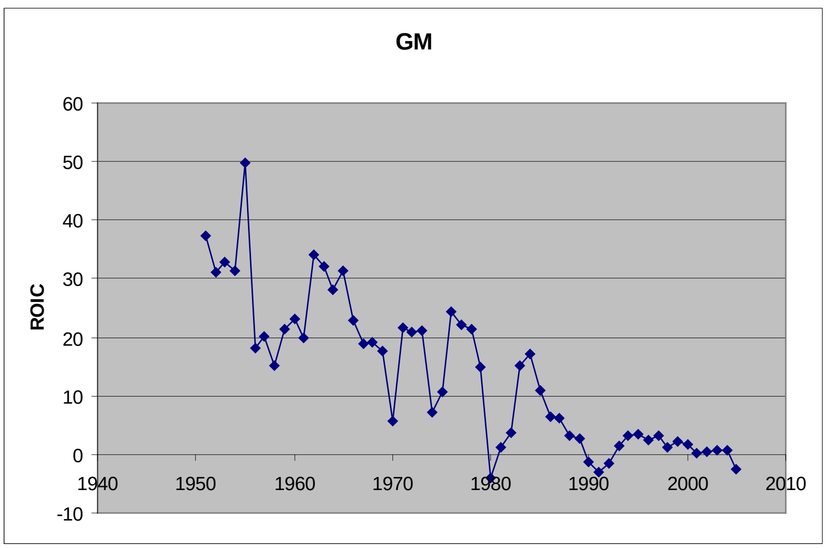

Figure 3.2 – GM's ROIC

Note in the figures below how Ford and GM responded to stiff competition coming from Toyota and others, by eliminating waste and reducing inventory. The result was an upward trend to increase *Inventory Turns* and to shrink lead times. Their goal was to become more competitive by better serving their customer bases.

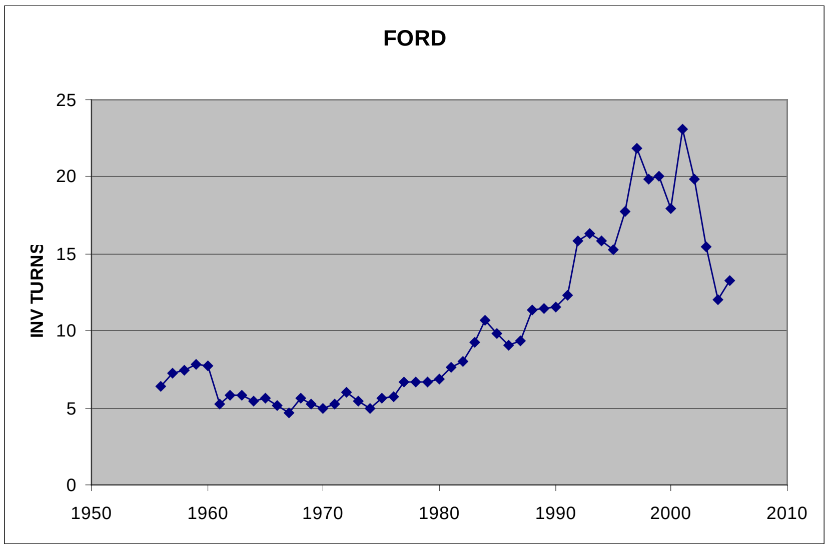

Figure 3.3 – Ford's Inventory Turns

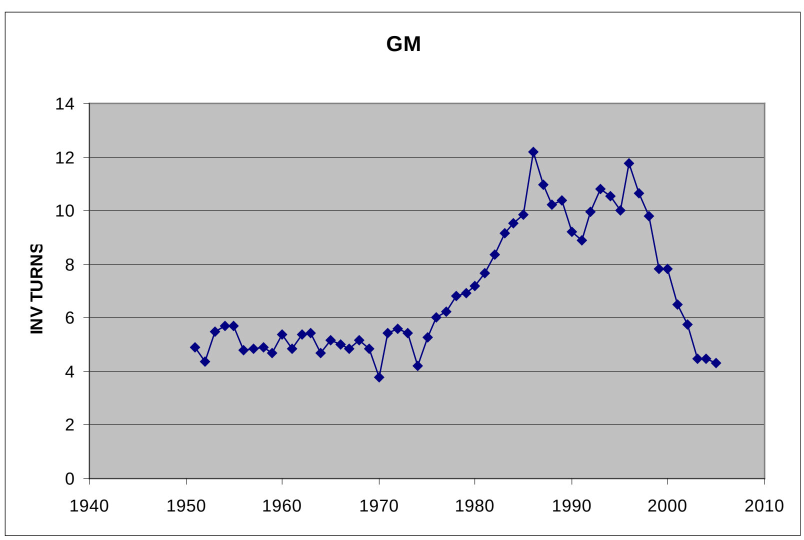

Figure 3.4 – GM's Inventory Turns

These data should serve as a motivator to traditional mass producers to initiate a program of process improvement, to reduce waste and to eliminate defects from systems. Furthermore, at the end of this work (see **Chapter Four**) statistical data will be presented as an evidence of the virtues of exercising cost discipline and production excellence.

3.4 Case Study: Dell versus Compaq (HP)

Let us now turn to a more contemporaneous example of production excellence, this time within the highly competitive computer manufacturing industry. The manufacturer of computers Dell typifed the quintessential example of a company that has applied Lean Six Sigma strategies to obtain higher levels of Information Velocity, thus maintaining Supernormal Returns longer than its greatest competitor, the former Compaq, now Hewlett-Packard.

Because of Dell's business model of accepting customer orders by phone and the Internet, instead of only selling computers to retailers, Dell was able to customize their PCs to a high degree, specifically fulfilling the needs of each particular customer, thus tremendously lowering its market entropy. This feat was accomplished by having extremely short lead times, which in turn lowered Dell's production entropy.

Normally Dell needed less than one week to make a personally tailored computer from ordering to delivering. The direct result of short lead times crystallized in the form of a high inventory turnover rate (defined previously as the number of times that inventory is totally sold – turned over – during a period of one year) and the ability to work with an inverted flow of cash. This meant to Dell that they collected money from customers before they had to pay any of their suppliers. Normally, companies pay suppliers before they receive cash from customers.

Lean Six Sigma was the strategy that allowed Dell to turn its inventory super fast and obtain an inverted flow of cash. In this case, being lean enabled Dell to reduce its inventory levels (raw material, WIP, and finished-goods), thus reducing holding and manufacturing overhead costs. By reducing overhead costs, Dell was able to have extra cash sitting around and to increase its net income and profitability, as long as its revenues from selling goods remained constant. This fortune cycle further boosted sales and revenue growth and aided Dell in preventing the accumulation obsolete products on its warehouses.

The table below shows a financial comparison between Dell and HP from 2001 to 2005. Note that even tough HP was a much bigger company at the time, with Market Capitalization of $100 billion (twice of Dell's), and it had a superior level of sales revenues ($70 billion per year), Dell was able to show a remarkable stock market growth topping HP several times and taking a bigger slice of the Personal Computer market share. If we think now in terms of Information Velocity, HP had much higher rates of entropy on its systems than Dell. Just compare *Inventory Turns* and *ROIC* for both companies.

Table 3.1 – Financial comparison between Dell and HP

DELL

	2005	2004	2003	2002	2001
Market Cap. (U$ billions)	48.75				
Sales *	55908	49205	41444	35404	31168
WIP *	78	58	69	72	61
Finished Goods *	169	173	97	70	63
Inventory *	576	459	327	306	278
Inventory/Sales	0.0103	0.0093	0.0079	0.0086	0.0089
WIP/Sales	0.0014	0.0012	0.0017	0.0020	0.0020
Finished Goods/Sales	0.0030	0.0035	0.0023	0.0020	0.0020
Inventory Turnover	91.3	91.3	121.7	121.7	91.3
ROIC	49.7	33.5	31.5	32.5	20.7
* in U$ millions	33.6	5 years average			

2005-2001 Inventory Turns was calculated from 365 / Days of Supply in Inventory

HP

	2005	2004	2003	2002	2001
Market Cap. (U$ billions)	99.67				
Sales *	86696	79905	73061	56588	45226
WIP *	1937	1749	1412	1667	1499
Finished Goods *	4940	5322	4653	4130	3705
Inventory *	6877	7071	6065	5797	5204
Inventory/Sales	0.0793	0.0885	0.0830	0.1024	0.1151
WIP/Sales	0.0223	0.0219	0.0193	0.0295	0.0331
Finished Goods/Sales	0.0570	0.0666	0.0637	0.0730	0.0819
Inventory Turnover	10.4	9.4	9.8	9.2	?
ROIC	7.5	10.0	7.2	-2.6	4.7
* in U$ millions	5.4	5 years average			

2005-2001 Inventory Turns was calculated from 365 / Days of Supply in Inventory

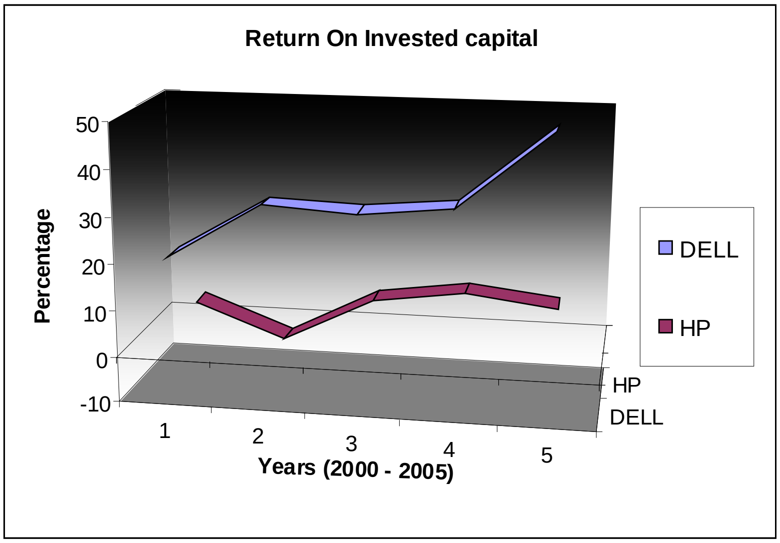

Figure 3.5 – ROIC for Dell and HP

The graph above shows the *ROIC* growth difference between the two companies. This case confirms the hypothesis of this work: when a company exchanges information with its market faster than competitors (i.e. high IV), the market rewards such firm with higher *ROIC* (the financial metric that indicates increased shareholder value). Consequently, an effective way to increase IV is to consistently produce goods in a Lean Six Sigma fashion.

3.5 Data Collection

After the initial pilot study, the researcher moved forward collecting financial information from several different industries. Some of these industries are: personal computers systems, communication equipment, photographic and business products and supplies, auto parts, conglomerates, auto manufacturers, farm and construction machinery, drug manufacturers, semiconductors, food manufacturers, electronic equipment, and many others.

Most of the collected data was extracted from the Wharton Research Data Services (WRDS) using the COMPUSTAT North America database. In most cases, data was collected trailing five years, beginning in 2001 and running through 2005. All available data was found either on Balance Sheets or Income Statements from annual reports. The most relevant data are included at the end of this work as part of the Appendix section. The results and interpretation of this rich data is found in the next two chapters.

4 Results

4.1 Statistical Analysis

The initial goal of this thesis was to identify the relationship between positive lean metrics and strong financial performance. The approach used to answer the research question was to perform a series of statistical analyses. The initial analysis consisted in running simple and multivariate linear regressions with data of hundreds of different manufacturing companies, seeking to identify how strong the correlation is between lean metrics and financial performance. Further analysis also included Student t-tests performed with those companies to demonstrate how statistically significant the difference is between the financial results of companies considered to be lean and companies considered to be mass manufacturers. The indicator of correlation used throughout this work was the coefficient of determination (R^2), or the square of the Pearson Product-Moment Correlation Coefficient.

4.2 Linear Regression

Linear regression is a form of regression analysis in which the relationship between one or more independent variables and another variable, called dependent variable, is modeled by a least squares function, called linear regression equation. This function is a linear combination of one or more model parameters, called regression coefficients. A linear regression equation with one independent variable represents a straight line. Linear regressions can be simple, thus having only one variable, or it can be multivariate, thus having several variables interacting simultaneously. In this research study both simple and multivariate experiments were performed in an attempt to find a meaningful correlation between lean metrics and financial performance.

4.2.1 Simple Linear Regression Analysis

The first experiment conducted was a simple linear regression made of a group of chosen manufacturing companies having their data averaged over five years (from 2001 to 2005). As mentioned in the previous chapter, two independent variables were used to run two different experiments, and they were: *Inventory-to-Sales ratio* (Inv/Sales) and *Inventory Turns*. The dependent variable employed on both experiments was *Return on Invested Capital* (*ROIC*). The initial results of the regressions did not reveal a strong correlation between any of the independent variables and the dependant variable, having at most a $R^2 = 0.l7$, which is considered to be weak in similar studies. (See **Table 4.1** for results)

4.2.2 Multivariate Linear Regression Analysis

The subsequent set of experiments was very similar in nature to the simple linear regressions. The difference this time was the presence of an additional variable called Dynamism. A full definition of dynamism is given in the following section.

Similarly to the simple linear regressions, the multivariate regression did not yield the expected strong correlation between lean metrics and financial performance. The main explanation for these results is that many factors can influence *ROIC* besides the ones used in this study (*Inventory-to-Sales ratio, Inventory Turns*, and *Dynamism*). Some of the factors not accounted by this research study are: brand equity, industry leadership and positioning, monopolies, intellectual property protected by patents, etc. As discussed in previous chapters, these and other factors influencing the financial performance are not included in this study because of the difficulty faced by researchers to quantify them.

4.2.3 Dynamism

Dynamism has been defined in the organization theory literature as turnover, absence of pattern, and environmental instability. Dess and Beard explained that the elements of dynamism include the rate of environmental change and the unpredictability of environmental change. In other words, dynamism accounts for change that is hard to predict and that heightens uncertainty for key organizational members (Dess and Beard 1984, 52-73).

Therefore, dynamism essentially measures demand volatility (sales variability), or the level of variation and uncertainty found in a given industry, or in a particular company, during a period of time. For instance, the dynamism for the food industry in the U.S. from 1986 to 2005 was found to be 0.115. This number indicates a very moderate level of demand uncertainty, with sales growing in an upward trend.

The interpretation of dynamism can be defined in the following terms. If sales revenues stay constant over time, dynamism (or demand volatility) is zero. If sales increase in a constant rate from period to period, dynamism (or uncertainty) will be small, but positive. Now, if sales decrease with a constant rate, dynamism will again be small, but negative. However, if the variation is erratic in either direction (positive meaning sales growth and negative meaning sales shrinkage) the magnitude of dynamism will be large with the respective positive or negative signs. The reason why this is so, is because the element of uncertainty is at play in a higher degree in this case (Ketchen, Thomas and Snow 1993, 1278-1313).

The reason why dynamism was chosen to be included as another variable in the linear regression analysis is because it indicates the importance of being flexible in face of an uncertain future and/or unpredictable environment. For instance, companies seeking to become more flexible through lean initiatives will have an advantage, if found in an industry showing erratic behavior, when compared with mass manufactures. This phenomenon is explained by the fact that lean companies are more agile and usually are more apt to scale up and down faster than mass producers.

Therefore, the underlying assumption used in this research study was that lean companies generally cope better with demand fluctuations in unstable industries and are able to reap higher financial results. Unfortunately, the multivariate linear regressions were not able to yield a strong correlation between lean companies having better financial performance if found in a turbulent environment. Again, the lack of strong statistical results can be explained by the high level of noise present in these types of analyses.

Even though the regression analysis containing dynamism did not yield a better correlation, this indicator of demand volatility still can be used as a powerful tool when making informed decisions, especially in consulting situations, because it reveals the ups and downs that can be expected in a particular industry over the years. In this case, the past can be used to predict the future. Thus, knowing the demand volatility or dynamism of a given industry is especially useful for mass manufacturing companies considering if they should change their production model to become leaner.

Finally, the way dynamism can be calculated follows a simple formula: set time periods as the independent variable (X) and sales revenues as the dependent variable (Y). Run a simple liner regression in Excel, and divide the resulted Standard Error by the resulted Coefficient, under the X-Variable (Dess and Beard 1984, 52-73).

$$Dynamism = \frac{Std.\,Error}{Coeficient} \tag{4.1}$$

4.3 Student T-Test

Because the results of both simple and multivariate linear regressions were not strong enough to make any particular inferences about lean metrics and superior financial performance, a t-test experiment was the next logical statistical tool chosen to answer the research question. The t-test null hypothesis (H_0) assumed that *ROIC* data sets from mass manufacturers were not significantly different from the *ROIC* data sets from lean firms, statistically speaking. The goal of this series of experiments was to reject the null hypothesis, showing that lean companies in fact present superior *ROIC* when compared with mass manufacturers.

Two sets of experiments were initially performed, one with matched-pairs and another one with a random sample. In all instances that a t-test was performed, both of the independent variables, *Inv/Sales* and *Inventory Turns*, and the dependent variable *ROIC* had their data points averaged, from the years 2001 to 2005. The decided confidence level for all experiments was set at 95%, assuming a two-tailed alpha error of

$\alpha/2 = 0.025$. This means that the study was willing to only accept 5% error in its results, thus making it compatible with other similar scientific studies. The critical t-values were data extracted from a **Standard Normal Distribution** table, following the rule: *Degrees of Freedom (d.f.) = Sample Size (n) – 2* (since two sets of data were used in the experiments) set against the chosen *95% Confidence Level*.

4.3.1 Matched-Pairs Experiment

The first experiment matched companies that were well-known in the press for being competitors and for their different approaches to manufacturing, one generally being a lean producer and the other being a mass manufacturer. The sample size for this particular experiment was of $n = 36$, and the critical value used was of $t = 2.032$.

The results indicated that the H_0 should be rejected when the variable used was *Inv/Sales* and *ROIC*, but not when the variable used was *Inventory Turns*. This phenomenon demonstrates that in general *Inv/Sales* explains better the variations observed in *ROIC*. These results were also reinforced by the fact that *ROIC* for lean firms was on average 10% higher than for mass firms.

Again, the results confirm the hypothesis of this work that lean companies have superior financial results when compared with mass manufacturers. The H_0 for *Inventory Turns* could not be rejected probably because this variable is not as well-suited to measure leanness as *Inv/Sales*. This initial conclusion is later confirmed by other sets of experiments described in the following sections. (See **Table 4.1**)

4.3.2 Random Experiment

In order to remove any bias from the matching study, a secondary set of experiments was performed using a new group of manufacturing companies. On this occasion, companies were not matched according to the arbitrary criterion used previously, in which some companies are defined to be *lean* and other companies are defined to be *mass* manufacturers.

This time, companies were randomly selected from a pool of all manufacturing firms by using an Excel random number generator, employing their respective industry SIC codes. The same basic requirements used with all the previous experiments, such as, of only including firms that presented annual sales revenue of above $2 billion, was again used here. The randomly selected companies were then sorted according to two variables: *Inventory Turns* and *Inv/Sales*.

The companies sorted according to *Inventory Turns* were organized in a descending order and divided in half. The first half was designated to be lean and the second half was selected to be mass producers. The major underlying assumption made was that true lean companies would turn over their inventories faster than mass firms and would present lower level of inventory when normalized by sales. The same process of separating companies was done again, but this time companies were sorted through the *Inv/Sales* criterion. Here they were organized in ascending order, and they were divided in two halves, the first half being lean and the second half being mass manufacturers.

4.3.2.1 Random Experiment I – Sorting by Inventory Turns

In the first experiment, all companies were sorted by the *Inventory Turns* criterion, with the lean companies presenting higher values. The results of using

Inventory Turns as a sorting criterion were insufficient to prove the hypothesis that lean companies present significantly superior *ROIC*. This particular experiment had a sample size of n = 38, a critical value of t = 2.0281, and presented a *ROIC* of only 2% higher in favor of lean companies. Once again, the t-test failed to reject the H_0 for both the *ROIC* and *Inventory Turns* values. Again, this result indicates that *Inventory Turns* is probably not the best variable to be used to explain the variations observed in *ROIC*. (See **Table 4.1**)

4.3.2.2 Random Experiment II – Sorting by Inv/Sales Ratio

In the second experiment, a totally new group of randomly chosen companies was sorted according to *Inv/Sales* criterion, and the results were surprising! Lean companies presented an average of *ROIC* 10% higher than mass producers, and the H_0 for all three variables (independent and dependent alike) were firmly rejected! This experiment had a sample size of n = 94 and a critical value of t = 1.9861. This means that *Inv/Sales* is probably a better variable to be used to explain the variations observed in *ROIC* of both lean companies and mass manufacturers. Note also that the sample size for this experiment was larger than the ones used in previous experiments. The effort to increase sample size originated from the researcher's desire to reduce variability and to increase validity of these tests. (See **Table 4.1**)

4.3.2.3 Random Experiment III – Sorting by Inv/Sales and Inventory Turns

This third time, another completely new set of random sample was selected, having a size of n = 94 companies. On this occasion, firms were sorted according to all possible criteria: *Inv/Sales*, *Inventory Turns,* and *Inventory Turns normalized by Sales* (Inventory Turns times Sales).

Two types of t-tests were performed. One test used all data points that were possibly available. This first test was essentially the same type of t-test done before, in other words to divide all companies into two halves and compare the first half (lean companies) against the second half (mass companies). The second test, compared the first quartile of data points against the forth quartile. The critical value for the experiment utilizing all data points (sample size n = 94) was t = 1.985, and the critical value for the experiment only using the data points found in the first and fourth quartile regions (sample size n = 25) was t = 2.069.

The particular procedure of picking the first and the fourth quartiles was followed to introduce a better distinction between lean firms and mass companies, since the potential difference in the levels of leanness between the company in the 50^{th} percentile and the company in the 51^{st} percentile is probably not very significant. (See **Figure 4.1**)

Side note: the graph below shows the relationship between *Inv/Sales* and *ROIC*. For instance, when *Inv/Sales* is approximately 18%, the predicted *ROIC* will be at 9%. Or when *Inv/Sales* is approximately 10%, the predicted *ROIC* will be at 14%, and so forth. The graph also shows that the function of *Inv/Sales* (blue curve) follows an approximated cubic function, whereas, the function of *ROIC* (pink curve) roughly follows a linear function.

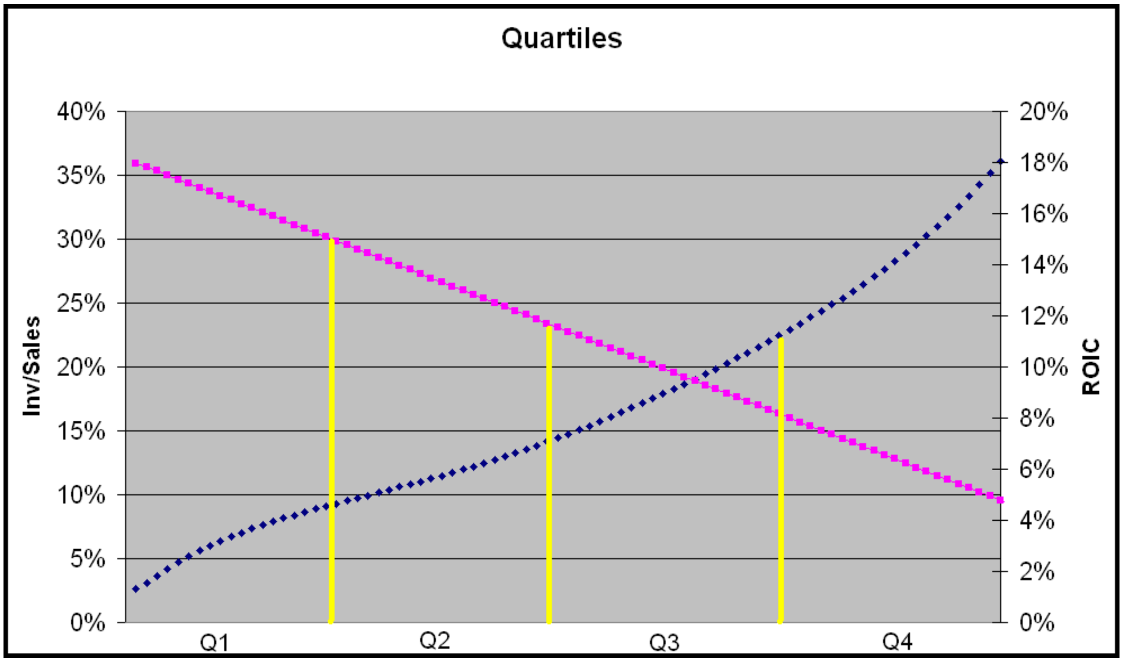

Figure 4.1 – Relationship between Inv/Sales and ROIC

Again, when data was sorted by the *Inventory Turns* criterion, *ROIC* was about 1% higher for mass producers! This unfavorable result appeared on both experiments, the one having all data points and the other only using the quartiles. Also, the H_0 used throughout of this study stated that the group of *ROIC* values belonging lean companies was not significantly different from the *ROIC* values belonging mass firms. Consequently, H_0 could not be rejected on both cases. Similar results appeared when the normalized criterion *Inventory Turns x Sales* was used. (See **Table 4.1**)

Now, when data was sorted using the *Inv/Sales* criterion, *ROIC* was on average 9% higher for lean companies (when using all data), and again 9% higher for lean firms (when using the 1st and 4th quartiles). The H_0 ended up being rejected on both instances for all variables, including the most interesting variable for this study: *ROIC*. Note that high levels of variation were found in most experiments. Look at the high standard deviations found in all variables and the small correlation between independent and dependent variables described in **Table 4.1**. A thorough explanation of why this phenomenon happened will be given later, in the next chapter.

4.4 Comparison of Other Studies

The goal of this study was not only to provide evidence that Lean Six Sigma companies present better Financial Performance Indicators (FPI) when compared to companies mass manufacturing their goods, but also to understand how the environmental forces (competitive and economic) within an industry might affect the various players.

The research also determined which variable was able to tell a better story in terms of a production model adopted and the resulting financial gains. In this case *Inv/Sales* explained more effectively the variations observed in *ROIC* than *Inventory Turns* was able to explain. This fact was quite surprising because *Inventory Turns* intuitively seemed to correspond better to elements of flexibility, such as short lead times, normally observed in lean companies.

By conducting this research, it was also clear that various factors influence the financial outcomes of a given company, and that the majority of these factors are not easily quantifiable for one reason or another.

Finally, the resulting data supported the initial hypothesis that companies employing a Lean and Six Sigma strategy in their production methods obtain on average an *ROIC* 10% higher than companies employing a more traditional mass scale production

(C.I. of 95%). The data also pointed out that lean companies have an average *ROIC* of 15%, while mass firms have an average *ROIC* of 6%.

The results mentioned above are fully corroborated by two other prominent studies published in two international scholarly journals (see **Section 2.7**). Claycomb published an article in the *International Journal of Physical Distribution and Logistics Management* arguing that the implementation of JIT can improve business performance. Their article provided evidence that companies that have substantially cut lead times, drastically reduced raw materials, work-in-progress, and finished goods inventory, effectively increased their asset turnover, return on investment (ROI), profitability, and return on sales (Claycomb and Germain 1999, 612). As cited before, these financial metrics are all closely related to *ROIC*. The findings of this particular study provided empirical evidence that companies that employed JIT strategies, or lean manufacturing, for over three years, were able to produce improved financial performance and competitiveness when compared with companies that did not employed such initiatives (Claycomb and Germain 1999, 612).

The other research was published in *The Accounting Review* journal in 2002, dealing with some of the evidences of JIT's profitability effects. Kinney and Wempe used a large sample of JIT adopters and matched non-adopters to examine the associations between JIT adoption and financial performance. They found that JIT adopters outperformed matched firms in profit margin and asset turnover, both components of return on assets (ROA), also over a three-year post-adoption period. The ROA changes for JIT adopters exceeded the changes of non-adopters by a highly significant difference. They also found that relative ROA improvement is concentrated among the earliest JIT adopters, especially among larger firms, which may have the most to gain from the JIT adoption. Their results clearly suggested a “first mover” advantage for early adopters, followed by dissipation of the advantage as JIT becomes more widely adopted. They also suggested that JIT, or lean manufacturing, makes the production setting more transparent, thus assisting line workers and management alike in realizing cost-savings through improvements (Kinney and Wempe 2002, 203).

Both research studies are strong evidence supporting the results found on this thesis that companies adopting a Lean Six Sigma strategy are prone to receive Supernormal Returns from their investments. The explanation for this phenomenon originates from Information Velocity Theory, which essentially states that lean companies are better prepared to respond to market demand, which is highly unpredictable, because they produce goods in small batches – low levels of inventories – and because they have short lead times. Supernormal Returns occur when companies generate ROIC well in excess of WACC, which in turn stimulates an explosive growth of stock prices.

Another important contribution offered by this thesis lays on the fact that this research employed two different methods of confirming the hypothesis about lean companies, matched-pairs and random sample; whereas the other two studies simply followed a matching strategy to support their hypotheses. Performing a random sample experiment added validity and credibility to this thesis because it removed possible personal biases that the researcher might have introduced in the experiment when matching companies. In fact, the results of random sample experiments validated the results obtained by performing matching-pairs experiments.

4.5 Summary of Results

The table below contains the summary of the results of the major experiments – matching-pairs and random sample – performed to support the hypotheses of this thesis. Keep in mind that the results seen under *Lean*, *Mass,* and *Difference* headings are displaying *ROIC* values.

Table 4.1- T-test results (ROIC) of experiments performed for Lean and Mass manufacturers

Experiments	Sorting Method	Data Type	Sample Size	Lean		Mass		Difference		t-test		Ho	Correlation (R^2)
				ave	stdev	ave	stdev	ave	stdev	critical	t		
Matched-Pairs	matching	all data	36	17	10	7	14	10	13	2.032	2.488	reject	0.1734
Random I	Inv.Turns	all data	38	11	22	9	12	2	18	2.028	0.350	fail	0.0501
Random II	Inv/Sales	all data	94	15	22	5	10	10	20	1.986	2.912	reject	0.0523
	Inv/Sales	all data	98	15	22	6	13	9	18	1.985	2.510	reject	0.0492
		quartiles	50	15	20	6	8	9	19	2.069	2.079	reject	0.0869
Random III	Inv.Turns	all data	98	10	23	11	13	-1	18	1.985	-0.223	fail	0.0005
		quartiles	50	11	19	12	15	-1	13	2.069	-0.132	fail	0.0001
	Inv.Turns x Sales	all data	98	10	17	10	20	-1	9	1.985	-0.138	fail	0.0012
		quartiles	50	13	20	7	16	6	12	2.069	1.261	fail	0.0053

5 Conclusion and Recommendations

5.1 Summary

The goal of this research was to verify the well-accepted proposition that companies having a lean operation and producing higher quality goods – six sigma – are financially rewarded for their determination to eliminate defects and streamline production. The theoretical basis for assessing the effectiveness of lean comes from Information Velocity (IV), a field of applied mathematics under Information Theory. Information Velocity states that companies that carry lower levels of inventory (one of the dimensions of being lean) will cause them to reduce the entropy of their internal production and distribution processes. Lower system entropy enables these companies to respond more quickly and efficiently to market changes. Metrics on inventory management, such as *Inv/Sales* and *Inventory Turns*, were chosen to be the independent variables because of their ample availability to the public through financial reports. Other variables, such as variety in product offering and lead time to fulfill market demand, could eventually offer a better explanation of how lean a company really is. But, such variables cannot be easily extracted from public records. Similarly, *ROIC* was chosen to be the dependent variable because it probably captures the financial effects of lean operations better than any other well-known financial indicator, and it is a variable widely available to the public. Remember, *ROIC* is a financial metric that quantifies how well a company generates cash flow relative to the capital it has invested in its business; and it is a good indicator to shareholders that the company management is wisely using the available resources to create value.

Once all the necessary elements to perform the experiments were in place, a set of simple and multivariate regressions were done. The initial results could not confirm a strong correlation between lean drivers and superior returns on investments. The experiment yielding the best results was the matched-pairs, having a $R^2 = 0.17$ (a relatively moderate indicator of correlation for this type of research). The reasons behind this moderate-to-weak correlation are several: many factors influence *ROIC* besides purely operational inputs, i.e. brand equity, patents, market monopoly, leadership, company's policies and strategy, perceived image, etc. Also, inventory metrics are only one type of indicator of leanness. Several other variables might yield better correlation results with *ROIC*, but because they are not widely available to the general public, they were excluded from this study. A final word explaining the overall poor correlation between the independent and dependent variables rests on the fact that a lot of noise is present when various companies from different industries and diverse backgrounds are put together in such a study.

Part of the scope of the project was to identify which independent variable (*Inv/Sales* or *Inventory Turns*) would explain better the variations observed on *ROIC* (dependant variable). The t-tests conclusively showed that the ratio *Inventory-to-Sales* (Inv/Sales), i.e. the percent of sales that was invested in inventories, explains better the variations seen on *ROIC*. See the results of the random sample t-tests for all three variables when companies were sorted according to *Inv/Sales*, and compare with the results of *ROIC* when the same companies were sorted according to *Inventory Turns*, i.e. the number of times the whole stock is turned or sold every year. (See **Table 4.1**) Also the correlation results (R^2) were much lower when data was sorted by *Inventory Turns*, as opposed to when data was sorted by *Inv/Sales*. Compare the matched-pairs and random sample experiments at **Table 4.1**.

It becomes evident why *Inv/Sales* correlates very well with *ROIC* when this variable is plotted against *Inventory Turns*. Because *Inv/Sales* has a good distribution of data points throughout the whole data range, it correlates very well with *ROIC*. Whereas, *Inventory Turns* explains well the variation observed on *ROIC* only when turnover is small, in other words for non-lean companies. Hence, *Inventory Turns* misses the opportunity to reveal lean companies, or the ones having higher inventory turnovers and their respective higher levels of *ROIC*. (See **Figure 5.1**)

Finally, high variation (standard deviation) observed in the t-tests are accounted by the fact that a random sample of companies from a great variety of industries and sectors are being organized and studied together. Note how much smaller the standard deviation of the difference of *ROIC* is in the case of the matched-pair study. (See **Table 4.1**) This is probably so because these companies are direct or semi-direct competitors within the same industry sector, which reduces variation.

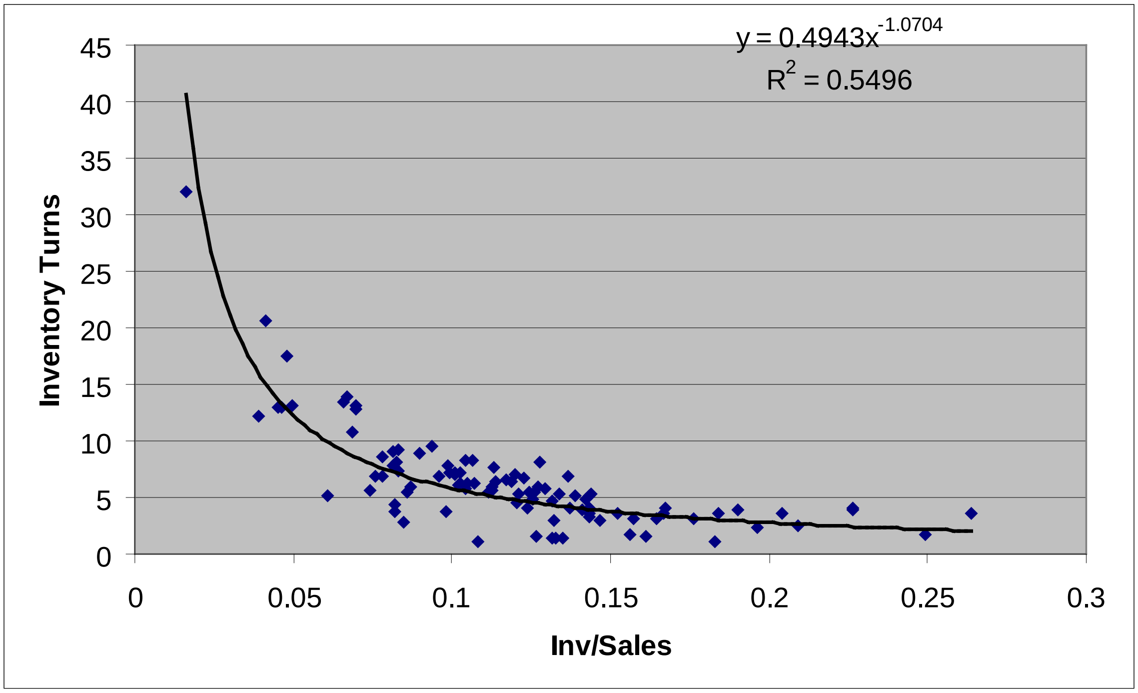

Figure 5.1 – Correlation between Inv/Sales and Inventory Turns

5.2 Conclusion

The results of the t-tests are robust enough to sustain the hypothesis that lean companies obtain higher *ROIC* when compared to mass counterparts, competitors and non-competitors alike. On average a lean company will yield *ROIC* 10% higher than a mass manufacturer (C.I. = 95%). This result should serve as an incentive for companies everywhere to adopt a Lean Six Sigma strategy. Note that in this study mass manufacturers (non-lean companies) had an average *ROIC* of 6% and lean manufacturers had an average *ROIC* of 16%. If *Weighted Average Cost of Capital (WACC)* for most companies is assumed to be around 10%, a plausible conclusion is that mass manufacturers, on average, destroy value faster than they are able to create value.

Another interesting point to make is that if these non-lean companies eventually move away from the traditional way of doing business and become lean, they could probably create value at a level 6% higher than their hurdle rates, again assuming that their WACC is 10%. This is good news not only for managers, but also for investors, because they can safely invest money in companies that on average yield a 16% return on total investments (*ROIC*).

Finally, a return to the mathematical principles of Information Velocity seems suitable to close the reasoning circle. Lean companies are only capable of achieving Supernormal Returns (ROIC>WACC and explosive stock growth) because they exchange information with the market faster and more efficiently than competitors. This feat is accomplished by carefully listening and understanding the customer base, producing only what the market expects, and delivering faster than competitors. Concluding, it is crucial not to forget to diligently analyze the market dynamics (dynamism) and the competitive forces operating within the various industries, especially if these companies want to develop a strategic edge over their rivals.

5.3 Observations

Most firms should strive to obtain Supernormal Returns by operating in two fronts. One, by realizing operation efficiencies through the application of a Lean Six Sigma production program, and two by creating disruptive innovations. In the search for the “holy grail” of higher returns it is important to remember that product development only affects the Information Velocity (IV) equation linearly, because it works with the numerator; whereas operations efficiency affects the IV equation geometrically, because it works with the denominator. (See **Section 2.4** and **Equation 2.2**)

Another very important factor to be considered when making investment decisions – from a managerial perspective – is the inherent risk of these two distinct strategies. Most CEOs agree that investments made in new product development carry considerably more risks than investments made in process improvement due to the nature of these two types of investment. As rule of thumb, it is assumed that Returns on Investments (ROI) originating from process improvement are usually much higher than ROI originating from innovation. Therefore, we can conclude that if a company wants to achieve business acumen in its industry, it certainly must invest fewer resources into developing and launching new products and more capital into process improvement initiatives.

5.4 Recommendations for Future Study

Future work should be primarily focused on understanding the relationships between uncertainty (dynamism) within a giving industry and the level of leanness a company should have to cope with sales variability. Two possible hypotheses for future study are:

1. Lean companies continue to thrive when the levels of dynamism (uncertainty) are high in an industry sector.

2. Mass manufacturers lag behind in face of high demand volatility, especially if the market size is shrinking due to meager sales.

The major contribution of furthering this research study could result from quantifying how important it is for mass manufacturers to become lean if they are found in a highly dynamic and competitive environment. For instance, industries that are highly regulated – especially the industries presenting stable growth rates and low competition – becoming lean might not be a priority. Possible reasons are simple: supplied goods are readily consumed by demand, or the returns of becoming lean might not justify the investment on training. However, stable industries are a rather rare occurrence. Nowadays, competition is fierce and industries are highly deregulated, which should prompt management to carefully consider the advantages of becoming Lean Six Sigma.

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APPENDICES

Appendix A – Shingo Prize Recipients

	Shingo Prize Recipients					
2007	Autoliv	Baxter	Delphi	Denso	Raytheon	
2006	Autoliv	TI	Delphi	Steelcase		
2005	Autoliv	BAE	Delphi	Boing	Lockheed	Takata
2004		TI	Delphi	Maytag	Raytheon	
2003	Autoliv	TI	Delphi	Medtronic	Lockheed	
2002	Tyco	Ford	Delphi	Bridgestone	Lockheed	
2001		Ford	Johnson C			
2000		Ford	Delphi		Lockheed	
1999	Wiremold		Delphi	OC Tanner		
1998			Johnson C			
1997			Johnson C			
1996		Ford	Johnson C			
1995	Nucor					
1994	J&J	Ford	Lucent	Alcatel		
1993	Wilson					
1992	Iomega		Lucent			
1991	Exxon					
1990	United Elec					
1989	Globe Metal					

Appendix B – List of Companies: Matched-Pairs Experiment

	LEAN			NON LEAN				DIFFERENCE			
	Inv Turns	Inv/Sales	ROIC	Inv Turns	Inv/Sales	ROIC		Inv Turns	Inv/Sales	ROIC	
DELL	69	0.013	34	8	0.094	5	HPQ	61	0.080	28	
NOK	13	0.046	35	7	0.092	9	MOT	6	0.046	27	
CAJ	3	0.143	16	7	0.083	-1	EK	-4	-0.060	17	
ITT	8	0.104	9	4	0.215	3	RTN	5	0.110	6	
WHR	7	0.111	9	4	0.147	12	SWK	2	0.035	-3	
GE	7	0.098	3	5	0.133	12	UTX	1	0.035	-9	
DHR	5	0.104	12	13	0.067	-16	DPHIQ	-8	-0.037	28	
TM	11	0.069	8	5	0.155	0	GM	6	0.086	8	
CAT	5	0.142	6	7	0.101	3	DE	-2	-0.042	3	
MRK	4	0.082	26	1	0.108	27	PFE	3	0.026	-1	
INTC	4	0.082	21	4	0.140	-9	AMD	0	0.057	31	
CPB	5	0.103	18	5	0.172	7	CAG	1	0.069	11	
K	7	0.071	10	6	0.103	6	KFT	1	0.033	5	
KO	5	0.061	31	8	0.052	21	PEP	-3	-0.009	10	
HOG	13	0.045	29	7	0.105	45	PII	6	0.059	-17	
AA	7	0.121	5	5	0.183	1	AL	2	0.061	4	
NUE	8	0.102	15	7	0.122	4	X	1	0.021	11	
CSCO	6	0.055	17	5	0.135	-7	ALU	1	0.080	23	
ave	10	0.086	17	6	0.123	7		4	4%	10	ave
stdev	15	0.035	10	2.575	0.042	14		15	5%	13	stdev
t-value	0.220	0.005	0.005	Probability of both samples coming from the same pop. α=.05							
z	1.23	-2.84	2.488	Critical z value is 2.04 according to the table							
Null H	fail reject	reject	reject	using α/2=.025, and d.f.=36-2=34				2.032			
Null H -> means of both sample sizes are NOT different											

Appendix C – List of Companies: Random Experiment

FIRST EXPERIMENT - random ex2.xls		*SECOND EXPERIMENT - random ex3.xls - Inv/Sales*	
LEAN	**MASS**	**LEAN**	**MASS**
APPLE INC	PPG INDUSTRIES INC	GANNETT CO	CUMMINS INC
PEPSI BOTTLING GROUP INC	LAFARGE SA -ADR	PEPSI BOTTLING GROUP INC	VOLKSWAGEN AG -ADR
NOKIA CORP -ADR	TOSHIBA CORP	PACCAR INC	CROWN HOLDINGS INC
GROUPE DANONE -ADR	DAIMLERCHRYSLER AG	HARLEY-DAVIDSON INC	SHERWIN-WILLIAMS CO
JOHNSON CONTROLS INC	KONINKLIJKE PHLPS ELC -ADR	NOKIA CORP -ADR	ROHM AND HAAS CO
PEPSICO INC	CELANESE AG	JOHNSON CONTROLS INC	UPM-KYMMENE CORP -ADR
PRAXAIR INC	LAUDER ESTEE COS INC -CL A	STEELCASE INC	ALLIANCE BOOTS PLC -ADR
TRW AUTOMOTIVE HOLDINGS CO	ROHM AND HAAS CO	COCA-COLA CO	TDK CORP -ADS
COCA-COLA CO	BALL CORP	ARVINMERITOR INC	ATLAS COPCO AB -ADR
FORD MOTOR CO-PRE FASB	ELECTROLUX AB -ADR	EQUISTAR CHEMICALS LP	SPX CORP
ARVINMERITOR INC	POSCO -ADR	TOYOTA MOTOR CORP -ADR	NOVARTIS AG -ADR
TAIWAN SEMICONDUCTOR -ADR	BUNGE LTD	MAGNA INTERNATIONAL -CL A	MEADWESTVACO CORP
TOYOTA MOTOR CORP -ADR	TOMKINS PLC -ADR	LAND O'LAKES INC	BRITISH AMERN TOB PLC -ADR
LAND O'LAKES INC	RHODIA -ADR	COLGATE-PALMOLIVE CO	HONEYWELL INTERNATIONAL INC
AIR LIQUIDE SA -ADR	JDS UNIPHASE CORP	XEROX CORP	SANOFI-AVENTIS -ADR
XEROX CORP	HONEYWELL INTERNATIONAL INC	COCA COLA HELLENIC BTTLG-ADR	ROCKWELL AUTOMATION
COCA COLA HELLENIC BTTLG-A	SANOFI-AVENTIS -ADR	LENNOX INTERNATIONAL INC	ABBOTT LABORATORIES
AVERY DENNISON CORP	ABBOTT LABORATORIES	AIR PRODUCTS & CHEMICALS INC	REYNOLDS AMERICAN INC
AVAYA INC	UNITED TECHNOLOGIES CORP	LOREAL CO -ADR	SHARP CORP -ADR
LOREAL CO -ADR	SHARP CORP -ADR	INTEL CORP	ASTRAZENECA PLC -ADR
FOMENTO ECONOMICO MEX -A	LILLY (ELI) & CO	MERCK & CO	SOLECTRON CORP
JOHNSON & JOHNSON	STORA ENSO CORP -ADR	NISSAN MOTOR CO LTD -ADR	NIKE INC -CL B
PROCTER & GAMBLE CO	WYETH	AUTOLIV INC	HITACHI LTD -ADR
BRISTOL-MYERS SQUIBB CO	HITACHI LTD -ADR	EASTMAN KODAK CO	CORNING INC
MOTOROLA INC	ABITIBI CONSOLIDATED INC	JOHNSON & JOHNSON	CATERPILLAR INC
FLEXTRONICS INTERNATIONAL	CORNING INC	PROCTER & GAMBLE CO	ARMSTRONG HOLDINGS INC
EATON CORP	CATERPILLAR INC	CEMEX SAB DE CV -ADR	CANON INC -ADR
AVON PRODUCTS	FEDERAL-MOGUL CORP	SMURFIT-STONE CONTAINER COR	FUJIFILM HOLDINGS CORP -ADR
UNILEVER COMBINED	CANON INC -ADR	UNILEVER NV -ADR	SARA LEE CORP
SVENSKA CELLULOSA AB -ADR	FUJIFILM HOLDINGS CORP -ADR	HONDA MOTOR LTD -AM SHARES	LEGGETT & PLATT INC
DEERE & CO	NEWELL RUBBERMAID INC	AVON PRODUCTS	STMICROELECTRONICS NV -ADR
NINTENDO CO LTD -ADR	PARKER-HANNIFIN CORP	SVENSKA CELLULOSA AB -ADR	MICRON TECHNOLOGY INC
NUCOR CORP	CATERPILLAR INC	CONTINENTAL AG -ADR	SCHERING-PLOUGH
ILLINOIS TOOL WORKS	GENERAL MOTORS CORP	DEERE & CO	AKZO NOBEL NV -ADR
DANA CORP	TEXTRON INC	NINTENDO CO LTD -ADR	ROCHE HOLDINGS LTD -ADR
AMERICAN STANDARD COS INC	OWENS-ILLINOIS INC	ILLINOIS TOOL WORKS	AGILENT TECHNOLOGIES INC
GENERAL MILLS INC	ROCHE HOLDINGS LTD -ADR	SEALED AIR CORP	VF CORP
CAMPBELL SOUP CO	AGILENT TECHNOLOGIES INC	AMERICAN STANDARD COS INC	DU PONT (E I) DE NEMOURS
KRAFT FOODS INC	BECTON DICKINSON & CO	ITT CORP	FORTUNE BRANDS INC
DANAHER CORP	DU PONT (E I) DE NEMOURS	ERICSSON (L M) TEL -ADR	SCHERING AG -ADR
ITT CORP	AK STEEL HOLDING CORP	CRH PLC -ADR	BAKER HUGHES INC
ERICSSON (L M) TEL -ADR	ARCELOR MITTAL -ADR	NOVA CHEMICALS CORP	METSO CORP -ADR
NOVA CHEMICALS CORP	METSO CORP -ADR	MATSUSHITA ELECTRIC -ADR	BAYER AG -ADR
JABIL CIRCUIT INC	SKF AB -ADR	PFIZER INC	SKF AB -ADR
REXAM PLC -ADR	CNH GLOBAL NV	IMPERIAL CHEM INDS PLC -ADR	BAXTER INTERNATIONAL INC
KIMBERLY-CLARK CORP	RAYTHEON CO	PPG INDUSTRIES INC	GENERAL DYNAMICS CORP
PFIZER INC	GENERAL DYNAMICS CORP	LAFARGE SA -ADR	TEMPLE-INLAND INC
EASTMAN CHEMICAL CO	GOODRICH CORP	BOEING CO	MONSANTO CO
HUNTSMAN INTL LLC	TENARIS SA -ADR	DAIMLERCHRYSLER AG	FIAT SPA -ADR

Some of the companies appear on both set of experiments because the set of active companies that have sales above $2 billion is composed of about 260 firms. Therefore, the chance of the same companies reappearing is about of 1 in 3.