AN APPLICATION OF LEAN PRINCIPLES TO PRODUCT DEVELOPMENT

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ABSTRACT

Product development is a catalyst, transforming ideas into products. This commercialization process is critical to the long-term viability of the business by fuelling revenue and earnings growth. Lean Manufacturing principles are core to Toyota's productivity and have been successfully adopted by many North American manufacturers. Toyota has also extended this methodology to its product development process. Several other methodologies, ranging from Six Sigma to Stage-Gate, exist both in manufacturing and product development. This analysis looks at applying these best practices.

An understanding of the corporate and industry environments serves as the foundation for this investigation. A review of best practices in manufacturing and development provides the theoretical framework with which to undertake a specific analysis at Creo. Three product development strategies are examined based on their relevancy, implementation and impact. These include modified Stage-Gate, TPDS and a hybrid approach. From this analysis, the report identifies commonalities and makes several concluding recommendations.

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GLOSSARY

Term	*Definition*
CTP	Computer-to-plate. The process of imaging printing plates directly with digital information as opposed to an analog process in which film is used as an intermediary
CTQ	Critical to Quality. Elements which are critical to the customer's quality requirements.
DCCDI	A DFSS acronym: Define, Customer, Concept, Design, Implement.
DFSS	Design for Six Sigma. A design methodology which attempts to create error-free processes from the start.
DMADV	A DFSS acronym: Define, Measure, Analyze, Design, Verify.
DMAIC	A Six Sigma acronym outlining the improvement process: Define, Measure, Analyze, Improve, and Control.
DMEDI	A DFSS acronym: Define, Measure, Explore, Develop, Implement.
DOE	Design of Experiments.
FMEA	Failure Modes and Effects Analysis. A process trouble-shooting methodology.
Heijunka	A Japanese term meaning production levelling, a key aspect of efficient flow in Lean Manufacturing.
IDOV	A DFSS acronym: Identify, Design, Optimize, Validate.
ISO9001	A quality-based accreditation administered by the International Organization for Standardization.
ISO14001	An environmental management standard to ensure products and services have the lowest possible environmental impact.
Jidoka	A basis of the Toyota Production System which translates as "automation with a human touch."
JIT	Just-in-time: An inventory management methodology whereby the movement of parts is coordinated to smoothly flow through the supply chain to meet customer demand and minimize inventory levels.

Term	*Definition*
Kaizen	Continuous improvement. A key activity in the application of Lean Principles.
KOS	Kodak Operating System – the application of Lean Principles at Eastman Kodak.
LDS	Lean Development Systems - the application of Lean Principles to the new product development function within a company.
LM	Lean Manufacturing – the traditional application of Lean Principles to a company's manufacturing processes.
Lean Principles	Originally a customer-focused manufacturing philosophy which attempts to do more with less by eliminating waste. Lean principles have now extended to multiple functions within an organization.
Muda	Japanese term for waste. Identification and elimination of waste is a critical aspect of a Lean system.
Poka-yoke	A Japanese term which is translated as error proofing a process.
Six Sigma	A quality focused manufacturing philosophy pioneered by Motorola in the 80's.
SPC	Statistical Process Control. A procedure used to monitor quality in a manufacturing environment.
TPDS	Toyota Product Development System. The methodology used by Toyota in its new product development process.
TPS	Toyota Production System. The manufacturing principles of the Toyota Motor Corporation which are considered to be the practical foundation of Lean Manufacturing.
Value Stream Mapping	A visual representation of every process in the material and information flow associated with the production of an item. This is a key activity in application of Lean Principles.
VOC	Voice of the Customer. A Six Sigma principle which highlights the importance of focusing on customer needs.
WIP	Work In Progress or Work In Process. Unfinished goods which represent one type of inventory categorization.

1 INTRODUCTION

1.1 Objectives – Definition of Success in New Product Development

Lean Manufacturing principles are now well established in many manufacturing operations and have demonstrated significant results in terms of cost savings, efficiency improvements, and ultimately customer satisfaction (Womack and Jones, 1996; Waurzyniak, 2005). However, the application of these practices to the product development process is less well recognized. Even the definition of a successful implementation is unclear. Although the application of Lean Manufacturing principles to product development has a broad scope, this specific analysis focuses on engineering operations at Creo, a subsidiary of Kodak. This report reviews current best practices in Lean Manufacturing and Product Development, examines specific opportunities at Creo, and makes appropriate recommendations as to how Creo can realize greater value from its product development process.

The success of this analysis depends on both a solid foundation in manufacturing best practices and a clear understanding of the objectives. Success in product development can generally be defined as using resources more efficiently to deliver value to the customer. Contributing factors and observable benefits include:

- shorter development times (reduced time to market)
- less capital expenditures and quicker payback periods
- product design manufacturability
- increased productivity and reduced cost of goods sold
- lower total cost of ownership for the customer

- product quality and reliability
- market acceptance
- a more competitive company

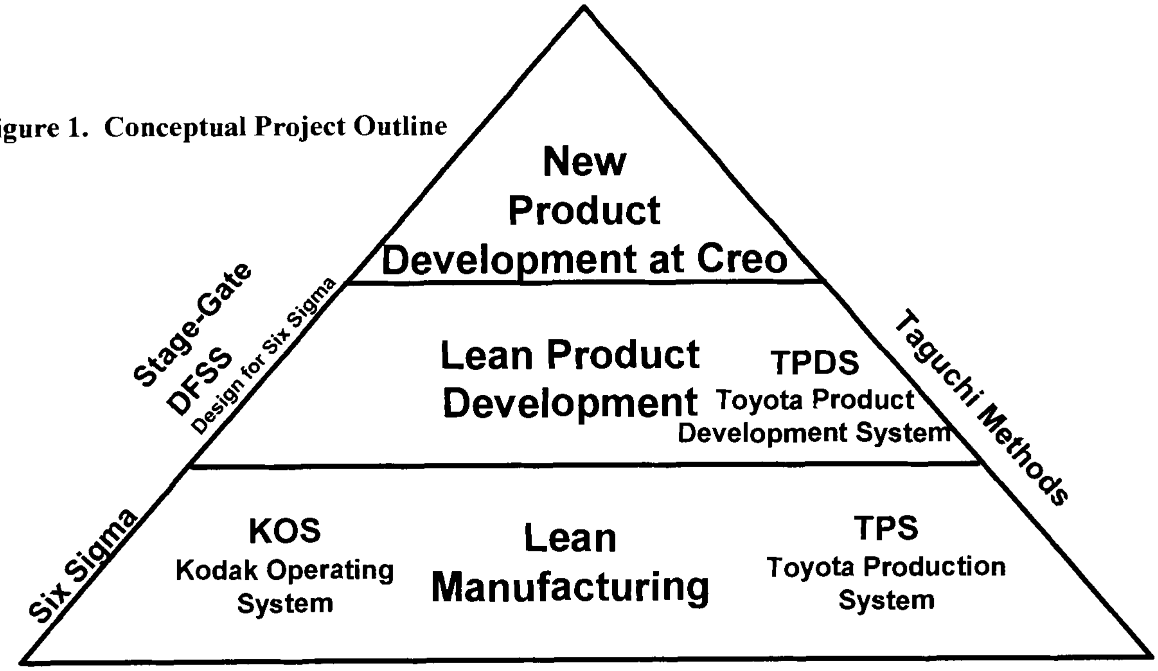
The specific objectives of this investigation into lean product development are as follows:

- Understand Lean Manufacturing principles and Product Development methodologies.
- Understand how other best-practices organizations, such as Toyota, apply Lean Principles in product development.
- Identify what opportunities exist to use Lean in Creo's product development process. Identify what changes need to be made to the current system.
- Comment on the implementation and estimate the impact of these changes.

1.2 Project Research Strategy

The collection of information to support this investigation relied on a variety of sources including academic journals, issued patents, corporate annual reports, filings from the US Security and Exchange Commission (SEC), popular press and a review of materials on the internet. A thorough knowledge of manufacturing best practices forms the core of this analysis. Furthermore, a clear understanding of both Creo's and Kodak's background, methodologies and objectives is necessary in order to arrive at coherent and appropriate final recommendations. The manufacturing best practices foundation is expanded by specifically applying the general findings to product development. Finally, the ultimate goal is the direct application of lean product development strategies to Creo's product development process. A conceptual representation of this framework is illustrated in Figure 1. Note that Lean Principles form the core of the analysis and are therefore contained within the pyramid; however, additional methodologies augment the investigation.

Figure 1. Conceptual Project Outline



This investigation required direct interaction with Creo's employees, environment and current practices. The majority of these activities occurred at Creo's Burnaby offices, with some discussions at the Annacis Island production facility. This process is both interactive and iterative in nature.

2 CORPORATE AND INDUSTRY OVERVIEW

Analysis of the industry, company and organizational dynamics forms the contextual framework for this investigation. Although the general philosophy associated with the application of lean principles to product development can be applied in a broad sense, the finer contextual details are required for a successful implementation. This chapter provides the necessary background with which to conduct our investigation.

The printing industry has grown immensely in the more than five centuries since Johannes Gutenberg first invented the printing press. Today, graphic arts is a multi-billion dollar industry employing millions of people. Printing press technology has experienced a number of revolutionary advances with the industry itself having rather interesting market dynamics. Consolidation, joint ventures and competition are all common amongst the major players in the industry. This section provides an external analysis of the organizations and industry. Consequently, all information represented within this section was obtained from materials in the public domain.

2.1 Creo's History, Products, Culture and Objectives

Creo was founded in 1983 by Dan Gelbart and Ken Spencer. The company's initial product focus was optical tape recorder devices for data storage. In the early 90's, Creo pioneered thermal computer to plate (CTP) technology which revolutionized the printing industry. Creo decided to provide a complete digital prepress system in order to facilitate easier customer adoption of the new technology. This strategy included input systems such as digital scanners, software providing workflow management solutions, proofing systems and output devices which transfer data onto printing plates. At the heart of the thermal CTP process is the SQUAREspot™ technology which precisely replicates digital pixels by providing uniform irradiance across each pixel (Creo, 2000, p. 13).

Creo's growth has been fuelled by product innovation and the company's success has been dependent on the generation and protection of its intellectual property (IP). The company's philosophy pertaining to its IP is best outlined by the following recent SEC filing (Creo AIF, 2005, p. 10).

> Our success and ability to compete are dependent in part on our ability to develop and protect our proprietary technology. Our practice is to file patents primarily in the U.S. and to make corresponding applications elsewhere when considered advisable to protect technology, inventions and improvements important to the development of our business. We also rely on a combination of copyright, trademark and trade secret rights, confidentiality agreements and licensing arrangements. As of September 30, 2004, we held approximately 328 patents worldwide, 211 of which were granted U.S. patents, and at that time we had 143 pending U.S. applications. In the past fiscal year, we were granted 33 U.S. patents and filed approximately 59 new patent applications in the U.S.

Throughout its history, Creo has maintained a belief of valuing its employees by providing a positive and challenging work environment. Since creativity and innovation are core to Creo's success, the work environment and culture must encourage such activities. By empowering its employees and decentralizing the decision-making process, Creo achieves its goal. In 2004, Creo was named one of Canada's 50 Best Employers by the *Globe and Mail's Report on Business* magazine. Creo was also the recipient of the Overall Leadership Award for large business at the Ethics in Action Awards for British Columbia. The company and its employees are guided by the following Creo Principles:

- We strive to be the best in the world in all that we do.
- We care about our customers, each other, our suppliers, partners and our shareholders.
- We do our absolute best to honour our commitments.
- We believe people are most effective and satisfied when self-managed and we will provide the tools, training and environment for this to occur.
- We strive to always act with integrity and fairness.

In its 2004 annual report, prior to the announcement of the Kodak deal, Creo identified three main priorities for the future. These included, earnings growth, strengthening the digital plate business and penetrating growth markets and regions (Creo, 2005, p. 21). According to Creo, earnings growth is fuelled primarily through cost reduction and 'driving the business forward.' The primary objective of earnings growth remains unaltered following the acquisition by Kodak and provides a strong mandate to implement Lean Principles across the organization. Expansion of the consumable plate business was designed to increases the company's competitiveness and its ability to offer a complete production solution to the customer. Although such a move enabled Creo to leverage its existing sales and distribution channels, this entry into a commodity business was a departure from its traditional business model. This initiative was fuelled by the acquisition of the Pietermaritzburg, South Africa and Middleway, West Virginia facilities. As of 2005, Creo was the fourth largest CTP plate vendor in the world. In

August 2005, Kodak announced that it would close the West Virginia facility as part of its product rationalization activities (Print On Demand.Com, 2005). The final goal of penetrating target growth markets and regions is complicated following the Kodak merger. A complete discussion is found in section 2.3.

In summary, we see that Creo is an organization with a strong corporate culture, a history of innovation, and a mandate for change. However, both the corporate direction and environment have been recently altered with the acquisition by Kodak. It is within this context that we will strive to recognize greater value for the company from the product development process.

2.2 Kodak's Financials, Structure and Reorganization

The Eastman Kodak Company is an organization in transition. The century old corporate icon and inventor of consumer photography has finally embraced the shift to a digital world. This transition began in earnest in 2000 under recently retired CEO Daniel Carp and is set to continue under his hand-picked replacement Antonio Perez. Kodak is using debt and the revenues from its high-margin, yet rapidly declining, film business to finance the restructuring of the company. In September 2003, Kodak slashed its annual dividend from $1.80 to $0.50 to fund the purchase of new digital initiatives. Investors reacted strongly to this move and sent Kodak shares down 18% (Deutsch, 2003). Coupled with this announcement was a pledge to grow annual revenue from $12.6 billion in 2002 to $16 billion in 2006. With sales of $13.5B in 2004, Kodak is slightly behind schedule but making positive gains (Eastman Kodak Company, 2005). However, Kodak is burdened with large reorganization costs and pension obligations. The new Kodak must be more competitive and prepared to accept reduced profit margins. Former CEO Daniel Carp acknowledges that the company's profit margin will drop from roughly 40% to 30%, but no further (Kher, 2005). The new Kodak will only faintly resemble the old film giant. This metamorphosis results from establishing new markets in the area of digital imaging technologies, known as infoimaging, and increasing productivity through a number of corporate initiatives.

Kodak has a truly global presence and tremendous brand recognition based on the success of its photography business. The new Kodak seeks to expand upon this base and diversify into the broader imaging domain, especially digital technologies. Consequently, Kodak's operations are divided into four main divisions (Eastman Kodak Company, 2005):

- Digital and Film Imaging
- Health Imaging and Information
- Graphic Communications
- Display and Components

Digital and Film Imaging (D&FIS) includes the traditional photographic films and papers, retail and wholesale photofinishing, in addition to digital cameras, printers and online picture services for both consumer and professional photographers. D&FIS accounted for 68% of revenue in 2004, as anticipated declines in the traditional film segment were offset by strong gains in digital media. The year 2005 should represent a significant milestone for Kodak as revenues from digital imaging (including the other business units) should exceed that of traditional photography.

The Health Imaging and Information division supplies both the medical and dental industries with traditional and digital imaging products and services. In addition to being the long-established industry leader in dental X-ray films, Kodak has ascended to the forefront in digital radiography. To complement equipment manufacturing, Kodak also provides digital information management services to a number of healthcare facilities. This business unit generated $2.686M or nearly 20% of net sales revenue in 2004.

Graphic Communications offers a variety of options to the printing industry as well as document scanning, archiving and IT services. Although 2004 revenues for this business unit are modest in comparison to other divisions, there is a tremendous potential for growth thanks to a number of strategic acquisitions which will be discussed later in this section. Kodak is well-positioned within the graphic communication market to capitalize on the transition to digital solutions.

The Display and Components division designs and produces leading-edge organic light-emitting diode (OLED) displays, imaging sensors and other specialty materials to original equipment manufacturers. Kodak's initial research into OLEDs has continued and resulted in the filing of over 150 patent applications in 2004. Kodak is well-positioned to benefit from its commitment to what many consider to be the next generation in display technology. In addition, Kodak's strong intellectual property portfolio will be prominent in the development of new flexible, lightweight plastic-based displays.

Massive re-organization is a consequence of Kodak's shift in strategy towards digital imaging technologies. Included in this transition are several acquisitions and divestitures. In addition to a change in dividend policy which increased retained earnings, the sale of the Remote Sensing Systems unit generated $725 million in cash. Much of this growth through acquisition strategy has been concentrated in the Graphic Communications group. These acquisitions include Scitex Digital Printing in January 2004 for $252 million and a number of NexPress related entities from Heidelberg in May 2004. The Creo and Kodak Polychrome Graphics (KPG) acquisitions, announced on January 31, 2005, completed Kodak's immediate growth in the graphic communication segment. Given the relevancy of the Creo acquisition to this report, it is discussed in greater detail in section 2.3. Kodak will acquire complete control of KPG from Sun Chemical Corporation in exchange for $817 million, payable over an eight year period. Assuming full ownership of this formerly joint venture significantly strengthened Kodak's position in the digital plate business. The acquisition of PracticeWorks in October, 2003 for $475 million bolstered Kodak's presence in digital radiography. Finally, several arrangements, including a 20% stake in China Lucky Film Company, have strengthened Kodak's position in emerging markets.

2.3 Kodak's Acquisition of Creo

Creo represents the final component of Kodak's growth through acquisition strategy in its Graphic Communications group. When the $980 million deal closed on June 15, 2005, Creo became a subsidiary of Kodak. As noted earlier, Creo fits nicely into Kodak's overall digital growth strategy. However, Kodak was not the only active participant in this transaction. On October 12, 2004 a group of dissident shareholders led by Burton Capital Management and Goodwood Incorporated, a Toronto-based hedge fund, began a proxy battle designed to unseat Creo's board of directors (Bolan, 2005, p. 16). This announcement led Creo, on October 15, to reveal that in July the board of directors had established a special committee of independent directors. The mandate of this committee was as follows (Creo, 2004)

> ...review strategic alternatives with the objective of enhancing shareholder value. The committee, management, and its advisors are charged with the evaluation of the company's business plan and the consideration of a full range of strategic options, including acquisitions, alliances with strategic partners, resale arrangements, business combinations, and the sale of all or a portion of the company's assets.

These activities culminated with the announcement of the deal on January 31, 2005.

In addition to silencing dissidents and rewarding shareholders, the Kodak-Creo acquisition created a consolidated leader in the commercial printing and plate industry. The complementary technologies and economies of scale should bring financial benefit to the company. However, despite the many advantages of the deal, it is not without its challenges. One of the most contentious aspects of the Kodak-Creo deal is Creo's established OEM relationship with Kodak rival Xerox. Creo's Spire colour print servers are a key component in Xerox's DocuColor printers and DocuColor iGen3 presses. As noted in Creo's 2004 Annual Report, Creo sought to increase revenues by expanding its digital printing business with Xerox (Creo, 2005, p. 5). Creo is also a major software partner with Xerox and recipient of Xerox's Software Partner of the Year award. Creo and DuPont have a worldwide strategic alliance in halftone and color proofing systems. However, Jim Langley, President of Kodak's Graphic Communications Group, has suggested that these relationships would continue as Kodak would establish a firewall between its and Creo's operations (Sherburne, 2005).

In terms of operations, one of the biggest differences between Creo and Kodak is profit margin. Summary financial statements for both Creo and Kodak are found in Appendix A and B, respectively. In the 2004 fiscal year, Kodak reported a gross profit margin of 29.4% while Creo enjoyed a 42.4% margin. However, despite this difference, Kodak's net profit margin was 4.1% compared to only 1.8% for Creo. Expenses were the contributing factor for this difference. Table 1 compares operating expenses between the two companies.

Table 1. Spending as a Percentage of Sales

	Creo		Kodak	
	2004	**2003**	**2004**	**2003**
Research and Development	13.3%	13.7%	6.3%	6.0%
Sales and Marketing	17.7%	18.5%		
General and Administration	9.8%	11.0%		
Total Selling, General and Administrative	27.6%	29.5%	18.5%	20.3%

Data Source: Creo and Kodak Annual Reports

Following the acquisition, it is expected that consolidation should reduce some of Creo's sales and administrative expenses. As a percentage of revenue, Creo spends more than twice as much as Kodak on research and development (13.3% to 6.3% in 2004). However, it should be noted that the two companies have adopted different rules regarding what they classify as R&D, as opposed to operating expenses. In absolute terms, Kodak spent $854M compared to Creo's net R&D spending of $84.5M. In its

2004 annual report, Creo indicated that it aimed to reduce its percentage R&D expense to 9% of total sales (Creo, 2005, p. 4). Reducing expenses associated with development of the consumable plate business is projected to help realize this goal. However, it also highlights the need for greater productivity in association with R&D resources and new product development.

The impact of the acquisition on Creo's stated objectives will be mixed. Earnings growth should be helped by the synergies between Creo's and Kodak's product offerings and greater economies of scale. Targeted growth should also be unhindered under Kodak ownership, especially given Kodak's stated objective to honour Creo's existing OEM and strategic alliances. Expansion of the digital plate business has been significantly altered following the acquisition since this segment represented the area of greatest overlap between the two companies.

Kodak's acquisition of Creo satisfied the immediate needs of both companies. Creo represents a great fit into Kodak's digital mandate and creates a true leader in digital pre-press technology. Product development plays a critical role in maintaining this leadership position and fuelling earnings growth. Additionally, this transition period provides an opportunity to reconcile best practices and implement change.

2.4 Industry Analysis – Graphic Arts (printing)

A 2002 report prepared for TrendWatch Graphic Arts estimated that in 2001 the global printing industry was a $409 billion business. Commercial printing represents the largest segment of this industry and the largest purchasers of prepress capital equipment. In the United States, commercial and retail printing was a $90.6 billion industry in 2003

(Euromonitor, 2004). Although the United States represents the largest single printing market, Creo's sales growth in Europe, the Middle East and Africa (EMEA) has been strong and revenue in EMEA has exceeded the Americas in the last two fiscal years (Creo, 2005, p. 24). The printing industry is dominated by small and medium sized businesses. In the US, the five largest companies account for only 25.2% of total market value (Euromonitor, 2004). The industry is very competitive with small margins. Consequently, cost, quality and speed are critical parameters. Innovation and new product development are key for Creo to be able to provide a sustainable competitive advantage to its customers.

Thermal CTP technology was one such innovation which Creo used to deliver value to its customers. Although there has been considerable growth in CTP installations over the past decade, the majority of the printing industry still uses traditional analogue imaging techniques. According to the August 2003 Vantage Strategic Marketing study, "Developing Market Opportunities For 'Direct-To' Technologies 2003-2008", only 35% of worldwide plate consumption was digitally imaged in the year 2003. This is projected to rise to 58% in 2008. Even in North America, the most digitally progressive market, CTP devices were used to produce about 60% of plates in 2003, and are projected to rise to 82% in 2008. At the end of 2004, industry sources estimated that approximately 22,500 CTP units were installed worldwide over 65 times more than in 1995 (Creo AIF, 2005, p. 5).

Growth in the digital plate market is complementing and exceeding that of CTP systems. According to industry sources, digital plate consumption is expected to increase from roughly 162 million metres^2 (1.75 billion ft^2) in 2003 to about 322 million metres^2

(3.46 billion ft^2) in 2008. That represents a compound annual growth rate for digital plates of approximately 15%. The digital plate business is a large and fast growing part of the graphic arts market. Industry sources estimate that total digital plate sales in 2004 were $1.9 billion of a total plate market of approximately $4.0 billion (Creo AIF, 2005, p. 5). Despite these strong growth projections, Kodak has indicated that the digital plate business will not be part of Creo's core growth strategy; hence, the importance of a lean new product development system within Creo's core capabilities.

Although Creo maintains a dominant market share in the CTP segment, both Creo and Kodak face heavy competition from Agfa and Fuji in the emerging visible light/photo-polymer plate market. This rival technology again highlights the need for a lean product development process and shortened development cycles.

3 A REVIEW OF BEST PRACTICES IN MANUFACTURING AND OPERATIONS

A solid understanding of manufacturing and operational best practices is necessary before attempting to apply these principles to the product development process. This section examines several particular methodologies including Lean Manufacturing systems and Six Sigma. Given the objectives of this report, specific relevance to Creo and Kodak will be noted.

3.1 The Kodak Operating System

Kodak has a well-defined corporate philosophy which seeks to increase productivity and profitability through the elimination of waste and the use of a number of best practices. This methodology is known as the Kodak Operating System (KOS). It began in 1999 as a manufacturing based improvement effort utilizing the principles of Lean Manufacturing. KOS is now being applied beyond manufacturing into areas such as Legal, Purchasing, Finance, R&D, Sales and Marketing. According to Kodak's Chief Administrative Officer and KOS creator, Charles Brown, "eventually all areas within Kodak and its subsidiaries will operate using KOS" (Brown, 2005).

The KOS mandate to eliminate waste incorporates three key areas: the customer, the process, and the worker. In order to deliver value to the company, KOS must enhance customer loyalty and satisfaction. Processes must be optimized to eliminate waste, provide superior quality and provide value to the customer. Finally, employees must be motivated to continuously problem-solve, embrace the KOS philosophy and deliver team-based results. These activities "enhance customer service, at the lowest possible cost, by eliminating activities that don't add value. It involves every person, job and place in the company" (Brown, 2005). The basic KOS philosophy is to do more with less. This includes world class customer service, improved quality, higher material velocity and an improved working environment. All of this is accomplished with less equipment, space, human effort, inventory and time.

KOS has delivered impressive results at Kodak (Brown, 2005). Manufacturing inventory reductions of 25% to 80% have been achieved. Product changeover times have been reduced by 50% to 90%. Individual kaizen projects have generated $300k to $1M in annual savings. Specifically, application of KOS at Kodak's Colorado Finishing facility, servicing the Health Imaging sector, has resulted in an 80% reduction in cycle time coupled with an 80% reduction in WIP. The collection of kaizen events at this facility has resulted in annual cost reductions of $7-8 million.

3.2 Lean Manufacturing Principles

The term Lean Manufacturing (LM) was actually coined at MIT in the mid 80's as part of the International Motor Vehicle Program (IMVP): an investigation of international manufacturing practices in the automotive industry. IMVP researcher, John Krafcik, noted that many operational practices of the Toyota Motor Corporation were "very lean". Although LM has only recently captured the attention of many western organizations, its foundations of quality and efficiency date back over a half century to the works of Edwards Deming and Walter Shewhart.

LM presents a different way of looking at one of the fundamental business equations (Shingo, 1981, p. 109):

Cost + Profit = Price

Using traditional thinking, one would determine a product's selling price based on production costs plus a given profit margin. This cost plus model does not provide incentives for operational efficiencies and quickly breaks down in highly competitive environments with downward price pressures. The alternative point of view can be expressed as:

Price (fixed) – Cost = Profit

This model clearly relates cost reduction to increased profits. Hence, there is a strong incentive to reduce operational costs and embrace the Lean credo "doing more, with less". However, one must not equate lean with just cost reduction (Hines, 2004, p. 995). Enhancing customer value is equally important to LM.

The financial impact LM is impressive. The Toyota Motor Corporation, through judicious application of LM principles known as the Toyota Production System, has ascended to become one of the world's pre-eminent automobile manufacturers. Table 2 shows a comparison of financial performance (net profit margin) for Toyota and other automobile manufacturers. This data reflects both the last fiscal year and five year averages. In both categories, Toyota has demonstrated far superior performance as compared to its North American-based competition. Even when compared to fellow Japanese automaker Honda, Toyota delivers better results. As a result of this success, Toyota is often held as the standard by which lean manufacturing practices should be judged.

Table 2. Profit Margin comparison in the Automotive Industry

Profit Margin	Toyota	Honda	General Motors	Ford
Last Fiscal Year	5.91%	4.51%	1.09%	2.28%
5 Year Average Return	5.03%	4.28%	1.33%	0.69%

Data Source: Reuters.com

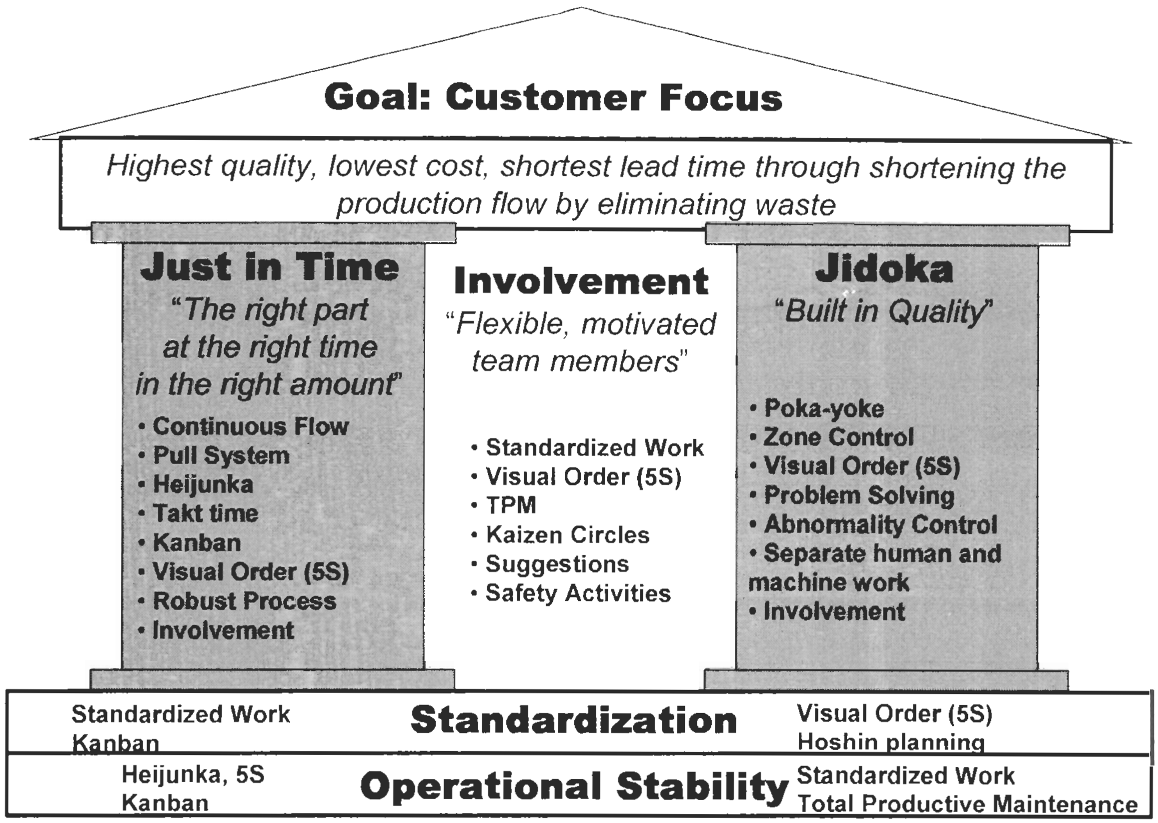
The subsequent analysis will begin by examining the Toyota Production System (TPS), the practical foundation of LM. In the subsequent five sections, I have built upon TPS and summarized what I believe to be the core principles associated with LM.

3.2.1 The Toyota Production System

The economic conditions in Japan following the end of World War II created a fertile environment in which to implement the manufacturing practices that would later become known as LM. Japan's manufacturing infrastructure was in ruins. The buying power of its citizens was very limited. The transportation and equipment needed in order to rebuild the economy were very diverse. In order to survive under these conditions, Japanese manufacturers had little choice but to implement a lean manufacturing system. With neither the capital nor markets to support dedicated equipment and mass production, the Japanese had to adopt a leaner, more flexible system. Similarly, since dedicated production lines were not feasible, both design and manufacturing implemented novel ideas such as common parts across several product lines, production line capable of quick change-overs and smaller production batches.

Under the guidance of Eiji Toyoda, TPS was implemented and refined by Shigeo Shingo and Taiichi Ohno. A conceptual understanding of TPS can best be obtained by considering what is known as the House of Lean Production (Dennis, 2002, p. 19). Figure 2 illustrates that Standardization and Stability form the foundation of TPS while Customer Focus serves as its apex. A company's core objective should be to provide the highest quality product, at the lowest cost, in the shortest amount of time. This is done by eliminating waste and implementing process cost reductions (Shingo, 1981, p. 145).

Figure 2. The Toyota Production System- House of Lean Production



Source: author based on Dennis, 2002

TPS relies on three principles: Just-in-time (JIT), Jidoka and Involvement. JIT is a rather poor translation of the original Japanese phase which is more suitable defined as "timely or well-timed" (Shingo, 1981, p. 98). Timely management of inventories and production levels helps eliminate waste. Jidoka focuses on quality and loosely translates as "automation with a human mind" (Dennis, 2002, p. 89). It also encompasses the final TPS principle of involvement. If workers feel something is wrong, they are empowered to act. As these factors also have a prominent role in LM, a more thorough discussion will be provided in the subsequent sections.

The adaptation of LM beyond the high volume, repetitive environment of automobile assembly requires careful analysis. Implementation of LM without an understanding of the processes and the organization can be disastrous. Such scenarios can often result when consultants or lean experts are mandated to make lean happen and neglect the central "involvement" pillar in their attempt. Another common criticism of LM is that it fails to cope with variability and has a limited role beyond high-volume manufacturing (Hines, 2004, p. 998). One should keep these limitations in mind when learning about LM and contemplating implementing it.

3.2.2 Elimination of Waste

Focusing on waste, or ***muda*** in Japanese, is a key aspect of LM. Any activity that does not provide value to the customer is inherently defined as waste. Since, in a typical operation, a remarkably small percentage of time actually contributes value to the product, there is a tremendous opportunity for waste reduction. Some estimates place the ratio of value to waste at 5/95. The original TPS defines seven types of waste (Shingo, 1981, p. 287). However, more recent thinking includes the misappropriation of knowledge or resources as an eight and even ninth waste.[1] Table 3 identifies and defines the eight wastes.

At Kodak, within KOS, the acronym TIMWOOD is used as an aid in remembering the seven types of wastes. Interestingly, these seven wastes are either physical or quantifiable; whereas, the eighth waste (knowledge disconnection) is more abstract. As noted previously, there is a huge opportunity for productivity gains within these more easily identifiable categories. The eighth waste is much more subtle, but can

[1] Knowledge Disconnection can be listed as Untapped Resources and Misused Resources (McCarthy,2005)

yield enormous gains. This idea is not unique to LM, as it is analogous to the idea of "engaging the workers' minds" espoused by Jack Welch during his tenure at General Electric (Slater, 1999, p. 147).

Table 3. The Eight Wastes in Lean Manufacturing

1. Transportation	Moving large batches or transporting WIP a long distance is waste. Material must flow through the plant, but movement should be minimized.
2. Inventory	The stocking of unnecessary raw materials, parts and WIP ties up capital and floor space. Enhanced product flow achievable through pull-based systems addresses excessive inventory.
3. Motion	Unnecessary motion by both humans and machines is waste. Ergonomics can reduce unneeded human motion.
4. Waiting	Production delays can take many forms including waiting for material to be delivered, waiting for a line stoppage to clear or employees waiting for a machine.
5. Overproduction	Overproduction (making things that don't sell) is the source of many of the other wastes.
6. Overprocessing	Operations which are not related to the customer's requirements do not add value.
7. Defects or Correction	Reworking defective material contributes no value to the customer. Material, time and energy are all wasted.
8. Knowledge Disconnection	Disconnects can occur between the company and its customers, its suppliers or its employees. Misuse of resources and miscommunication also represent waste.

Source: author based on Dennis, 2002

A value stream analysis at both the macro and micro level is a valuable tool in order to identify and eliminate waste. In the preface to its 2004 Annual Report, Creo outlines a preliminary macro level value stream map for the printing process. Interestingly, such analysis in the early 90's would have identified the wastefulness of the intermediate imaging to film step and highlighted the opportunity for computer to plate. A much more detailed analysis of an individual process step provides specific opportunities for improvement. Value stream mapping can be a very rigorous process with particular symbols used to identify processes, flows and opportunities; however, it can also be adapted to individual situations. The main benefit of this tool is to create a focus on improving the process.

3.2.3 Process Flow

Efficient process flow minimizes waste. The Just-in-Time (JIT) processing methodology helps achieve this goal by delivering just what is needed, when it is needed. The JIT philosophy follows a few simple rules (Dennis, 2002, p. 66).

- Don't produce something unless the customer has ordered it.
- Level demand so that work may proceed smoothly throughout the plant.
- Link all processes to customer demand through simple visual tools.
- Maximize the flexibility of people and machinery.

These ideas support the concept of "pulling" materials through the system rather than the traditional philosophy of "pushing" material through the factory. "Pull" systems are demand based rather than forecast driven. Such a system relies on the efficient flow of material through the factory rather than large inventory levels. Two supporting components of this system are levelled production or *heijunka* and a visual synchronization known as *kanban*. However, it is important to understand the dynamics of the business and the order process. Pulling is not a replacement for planning. Although LM may be at philosophical odds with forecast based planning, LM and ERP (Enterprise Resource Planning) can, and do, coexist within an organization (Bartholomew, 1999). Toyota still depends on a forecast plan in order to schedule its annual production (Hines, 2004, p. 998). However, with its LM system it is able to quickly adjust those forecasts based on pull signals from the dealerships.

3.2.4 Quality

Since defective products fails to provide any value to the customer, quality is one of the main principles governing LM. The purpose of this objective is to drive the defect rate to zero (Shingo, 1981, p. 329). The *jidoka* concept, or automation with the human touch, was advanced by Shigeo Shingo. It relies on reducing defects by improving process capability, identifying defects and quickly rectifying the situation through a quick feedback system. Prevention offers one of the easiest options to reduce errors. The concept of *poka-yoke* or error-proofing is a simple, low-cost technique for preventing or detecting error situations before they occur. In general, poka-yokes are designed for the workplace, have high reliability, and provide immediate feedback with low maintenance (Dennis, 2002, p. 92).

Manufacturing high quality products requires reliable equipment in addition to a focused workforce. Total Productive Maintenance (TPM) moves the organization away from the reactionary process of repairing broken down equipment into a preventive and predictive mindset. While equipment downtime can be a major source of waste, inefficient and defect-producing machines are even more sinister. A TPM system enhances the stability foundation necessary in Lean Manufacturing.

3.2.5 Workplace Organization

Workplace organization assists both process flow and quality. The 5S system was implemented to provide a de facto standardized housekeeping protocol amongst manufacturing operations. Standardization and organization through the 5S process also reinforces the stability within the Lean Manufacturing methodology. The 5S activities are both continuous and sequential in their application. However, in order to achieve real value from this system, it is necessary to implement all five activities: a 5S approach rather than a 3S system (Chapman, 2005, p. 27). The 5S methodology began in Japan, but has subsequently been translated into English. Table 4 provides a listing of the five S's, in both Japanese and English, as well as a brief description.

Table 4. The 5S System in both Japanese and English

S1	Seiri	Sort	Separate and eliminate unneeded items.
S2	Seiton	Straighten or Set-in-order	Compare 'what it is' with 'what it could be'. Arrange layouts to minimize time and effort.
S3	Seiso	Shine or Scrub	Keep the machines and workplace clean.
S4	Seiketsu	Standardize	Use simple visual standards to highlight when things are amiss.
S5	Shitsuke	Sustain	Through self-discipline, maintain and promote 5S.

Source: author based on Imai,1997

The 5S process begins by *sorting*, which is usually accompanied by a red-tagging activity in which unneeded items are marked for removal. To achieve maximum benefit, this activity should occur with regular frequency. *Setting in order* helps improve the process flow, eliminate waste and move the system towards and to a new, improved state. The use of maps, colours and outlines helps create an easy to use visual system in which information can be conveyed at a glance. A clean workplace helps promote a safe and positive environment; hence *shining* is a key aspect of 5S. A clean workplace also makes it easier to identify abnormal conditions such as a leaky piece of machinery. In order to maintain the first 3S activities, it is necessary to embrace the final two. *Standardization* is best achieved through the use of clear, simple and visual standards (Dennis, 2002, p. 34). Additionally, 5S should become part of the standard work process.

This ties into the *sustain* aspect of 5S, which must be rooted within the corporate culture. Just as involvement is key to Lean, it is also critical to 5S. Promotion, communication and training are all activities that should be encouraged amongst team members in order to accomplish this goal.

3.2.6 Standardization

A number of the previously described activities support the idea of standardizing the manufacturing process. The idea of standardization goes back to Henry Ford and the creation of the assembly line. In fact, in the early days of the westernization of LM, *The Economist* identified several lean principles that can be attributed to Ford (anonymous, 1992, S5). However, Ford's concept of mass production represents a significant divergence in the two philosophies. Process layout and product standardization can have a significant impact on the overall efficiency of the organization. It is important to optimize overall efficiency rather than individual efficiency. This "big picture" view should be maintained throughout most Lean activities.

3.3 The Six Sigma Methodology

Although Motorola pioneered the Six Sigma initiative in the mid 80's, Kodak was an earlier adopter of this methodology. Lean and Six Sigma can harmoniously coexist within an organization. Since 1992 Kodak has been an active participant in Six Sigma and a charter member of the Motorola Six Sigma Consortium. Six Sigma is a quality-focused approach with the objective of 'total customer satisfaction' through the reduction of process variation. By strict definition, a six sigma process is one with a defect rate of 3.4 parts per million. However, Six Sigma as a methodology can be used to improve process results by reducing variation. At Kodak, two main Six Sigma titles are used: Black Belts and Champions. Black Belts are expert Six Sigma practitioners who have completed extensive training and a major applied project. Champions are business leaders who support the initiative and identify projects. In other organizations, individuals who have received training in core Six Sigma principles and have completed an applied project are given the title Green Belt. The following sub-sections examine two key concepts associated with Six Sigma.

3.3.1 Tenet 1 - The Voice of the Customer

The customer focus associated with the Six Sigma methodology is highlighted by the Voice of the Customer (VOC) principle. Process teams are reminded to understand the needs and wants of their customers, be it internal or external. As simplistic as it may sound, one of the most basic steps in process improvement is identifying customers and their needs. This is often ignored in many manufacturing environments and can be completely missed or overlooked in research and development labs. Once customer needs are established, it is necessary to identify the most important attributes and determine ***critical-to-quality*** (ctq) characteristics. Establishing specifications that define customer expectations with respect to ctq's provides clearly identified goals for both product and process improvement. The procedure by which to achieve these goals is discussed in the following section.

3.3.2 Tenet 2 - The DMAIC Principle of Process Improvement

The DMAIC principle is a core tenet of Six Sigma. It can serve as a foundation of the organization's quality program and the methodology by which one can realize process improvements. DMAIC is an acronym defining the steps by which one should implement a quality-based process change: ***Define, Measure, Analyze, Improve and Control***. One must begin by defining the problem and the desired outcome. This can be applied at a rather high level to identify quality goals within the organization or much more focused at the process level. Rather than immediately moving into the improvement phase, one must have the diligence to both measure the associated variables and carefully analyze the problem. A number of analysis tools are available within a Six Sigma practitioner's toolbox, with templates and discussions available on the internet (iSixSigma Quality Tools and Templates, 2005). With the appropriate data and analysis, an improvement plan can be put into place. This must be followed up with continued observation and control loops which create both an iterative process and a means to monitor effective implementation of a successful process.

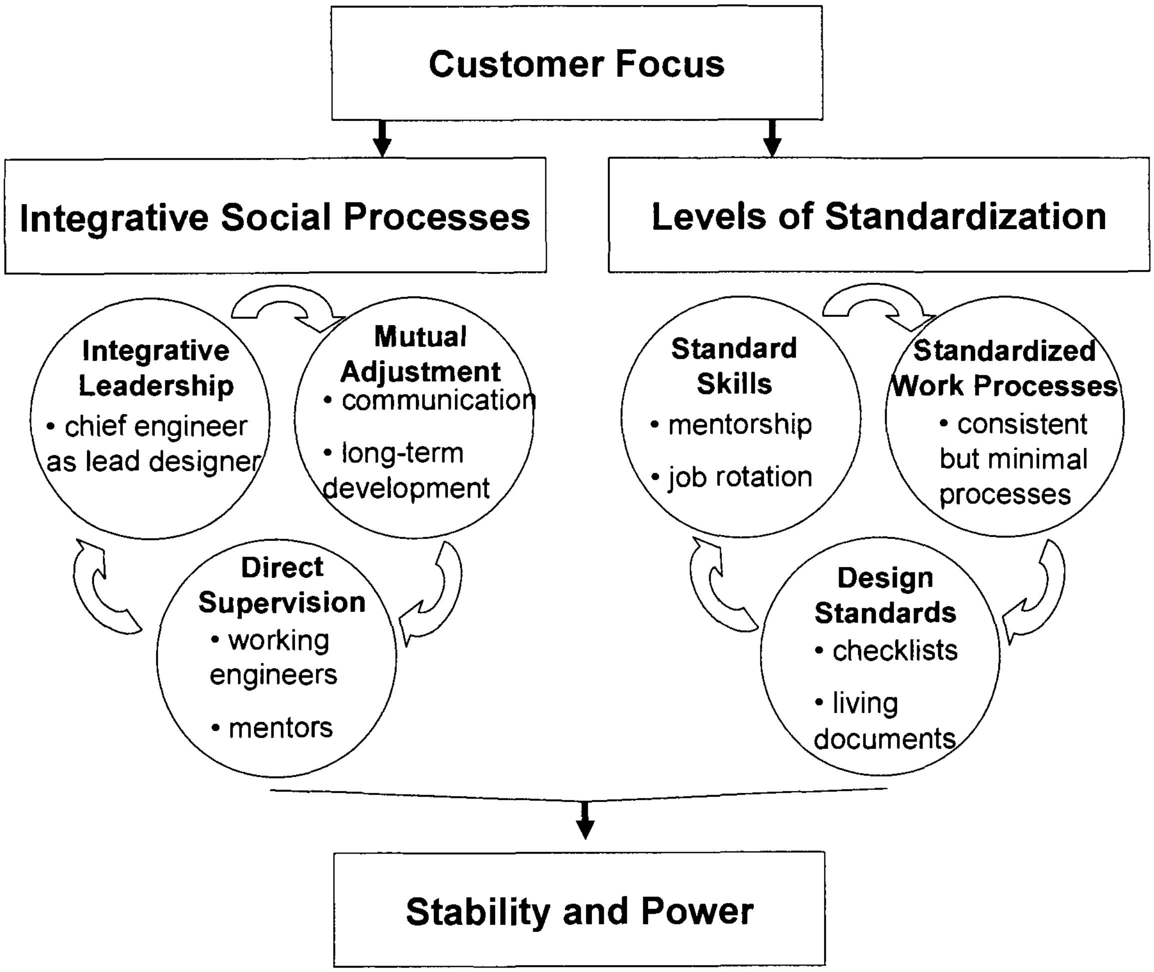
4 A REVIEW OF BEST PRACTICES IN NEW PRODUCT DEVELOPMENT

The importance of solid new product development to the sustainable long-term success of the organization has been known for quite some time. In addition to lean-based product development methodologies, a myriad of strategies exist with no one practice identified as the clear choice. As with most sources of competitive advantage, a successful strategy must be tailored to company resources and industry factors. Several new product development schemes will be reviewed in this section. Notice that both the Toyota Product Development System and the Design for Six Sigma methodologies are extensions of the corresponding manufacturing practices. Taguchi methods can be applied to both product development and manufacturing, whereas Stage-Gate serves as both a methodology and a roadmap for the product development process.

4.1 TPDS: The Toyota Product Development System

The Toyota Production System (TPS) has been acknowledged as a source of Toyota's competitive advantage; however, it is not the only reason for the company's success. The Toyota Product Development System (TPDS) is perhaps an even greater asset to the company (Sobek et al, 1998, p. 38). Researchers in the Japan Technology Management Program at the University of Michigan spent over five years investigating the product development practices at Toyota. The results of this study provide the most thorough analysis of TPDS to date and form the foundation for this section. The *Harvard Business Review* article by Sobek, Liker and Ward is the source for much of the material presented in this section. The conceptual framework and interdependencies of TPDS is illustrated in Figure 3.

Figure 3. Coordination of the Toyota Product Development System



Source: author based on Sobek et al, 1998

As illustrated in the figure, half of the successful implementation of TPDS is attributed to the organization's operational culture or integrate social processes. These factors are based on leadership, communication and mentoring. Complementing these social factors are standards-based protocols including skills, processes and design. Although it must be acknowledged that it is the integration and coordination of these factors which ultimately produces success, it is beneficial to examine each component individually. This examination will begin with the cultural factors.

As in any organization, leadership has a tremendous influence on success. In TPDS, the Chief Engineer has full responsibility for the particular project, but does not have direct power over any one functional group. This is certainly not a new or revolutionary concept as analysis of the automotive design process in the early 90's identified the "heavy weight project manager" as a key component in successful organizations (Clark and Fujimoto, 1990, p. 114). However, a Chief Engineer assumes a greater role as the project's lead designer. This organizational structure allows team members from different functional groups to represent differing perspectives. Creative conflict, if managed properly, can generate superior designs. The Chief Engineer must recognize these localized issues while still seeing the complete picture, designing for manufacturability and maintaining a customer focus.

Communication is a key success factor in any group dynamic. TPDS recognizes the importance of face to face communication, but also does not downplay the role of effective written communication. These options should be used in a complementary and efficient manner. Meetings must be focused and participants must be prepared in advance. Regularly scheduled meetings are discouraged. Instead, written communication serves as the first step in problem solving. Standard forms, named A3's after the paper size (roughly 11" by 17"), are used to encourage short and concise reports.

Standardization, a core principle of Lean, also enables report readers to quickly assess the information.

Mentoring helps to disseminate knowledge through the organization and forces those in supervisory roles to remain in touch with their technical expertise. Supervisors and higher level managers are deeply involved in the engineering process. Functional supervisors work closely with new hires and junior engineers. Although such a situation runs counter to the notion of self empowerment, the TPDS relationship is closer to a mentor-student relationship than that of boss-subordinate. The US norm of engineers transitioning to managers and abandoning engineering work does not flourish in TPDS.

Specialized engineering skills are needed by all companies in order to bring new products to market. Hence, training is an important aspect of an engineer's career growth. Toyota places a heavy emphasis on internal training. An engineer's skills are augmented by job rotations within his or her functional group. Unlike most North American companies which provide broader job rotations, Toyota focuses on functional excellence. However, at the senior level, engineers are given broad rotation which helps create a big picture vision of the new product development process.

TPDS aims to standardize the process without creating an outdated and unmanageable bureaucracy. Standards are consistent yet minimal. Toyota's vehicle development process is highly consistent from model to model, with regular milestones. Although the process has a high degree of standardization, the implementation is allowed to vary based on individual project requirements. Flexibility, coupled with a common understanding of the system and a desire for continuous improvement, enables the process to work. Standards are kept simple and are maintained by the people who use them. Development of the product and the process standards are considered to be inseparable.

Like process standards, design standards are also considered living documents. Outside of Toyota, design standards are often seen are being outdated or inhibiting to innovation. However, TPDS maintains a thorough design checklist to serve a guide and ensure manufacturability of the final product. Checklists also make it more likely that components will meet expectations with respect to functionality, quality and reliability. Since these lists are continually updated, they help facilitate continuous learning and serve as a repository for engineering design knowledge.

TPDS is designed to operate as a multi-project strategy. This interdependency creates a system in which best practices can be shared across projects and engineers gain experience to differing products and teams. The success of TPDS is evidenced by Toyota's product development times of 20 to 24 months from design to production. Recently, Toyota announced that it intended to reduce this development time to just 12 months. This industry leading performance highlights the success of TPDS and provides Toyota with a sustainable competitive advantage.

4.2 The Toyota Prius – An Application of TPDS

One of the historical criticisms of Japanese product development methodologies is that they fail to foster true innovation. The nation's reputation is that of a fast-follower rather than an innovative first mover (Teresko, 2004, p. 22). However, the Toyota Prius not only breaks this stereotype, but also represents a departure from traditional product development within TPDS. The Prius hybrid gas-electric vehicle represented significantly more advanced product development process than that required for a model redesign.

The concept model Prius was introduced at the Tokyo Motor Show on October 27, 1995 after being formally approved by corporate officials on June 30, 1995. In December 1995, Toyota announced that its hybrid vehicle would be available for sale in Japan in two years. Remarkably by North American standards, Toyota delivered on this promise and shipped its first Prius on December 10, 1997 (Vasilash, 2003). The US model was introduced in August 2000 after concerns about the car's ability to perform in variable climates had been addressed. In 2004, Prius became the first ever hybrid to win Motor Trend's Car of the Year award.

Prior to examining the product development process, it is enlightening to examine Toyota's rationale for embarking on this endeavour. Toyota's corporate philosophy includes environmental responsibility throughout the organization. In January 1992, Toyota introduced its "Earth Charter" which created an environmental directive for the company. This mandate is realized through the development of low emission vehicles and environmentally sustainable manufacturing practices. All of Toyota's North American facilities have received ISO 14001 Certification for superior Environmental Management Systems. Higher gasoline prices, especially in Japan, coupled with government mandates on emission standards created a market opportunity. Furthermore, through market research Toyota established that consumers were willing to pay an additional $5,000 to purchase an environmentally friendly car over a similar gas alternative (Business Week, 2000). This clearly defined market need provides the context for Toyota's development process.

The Prius was build upon a variety of fundamental research and development, dating back to the mid 70s (Dawson, 2005, p. 20). Toyota's hybrid initiative can be traced back to earlier work on electric vehicles. These vehicles were plagued by prohibitively short battery lifetimes, but the experience provided Toyota engineers with a core competency in power management and circuitry. This technology, now known as Hybrid Synergy Drive, is the basis for the Prius and all of Toyota's future hybrid vehicles. Hybrid development was just one of a collection of alternative energy, low emission vehicle initiatives which included fuel cells, natural gas, direct injection diesel technology and variable valve timing. This set of initiatives highlights the multiple project approach of TPDS and created a sense of friendly competition within the company.

The most notable TPDS principle which applies to the development of the Prius is integrative leadership. Both Managing Director Hiroyuki Watanabe and Chief Engineer Takehisa Yaegashi have over three decades of experience at Toyota. Additionally, Toyota was able to draw upon its early work in alternative energy vehicles to create a standardized skill-set. It also chose to keep the entire development project in-house, as it was deemed to be in Toyota's long-term best interest to do so. At first glance, the Prius appears to depart from the TPDS principle of standardization. Unlike many Toyota vehicles, the Prius does not share any major components with other product lines. In fact, when the first Prius was launched in Japan, it included more than 300 patents. The second-generation vehicle has 370 patents (Vasilash, 2003). However, despite the considerable amount of innovation, the Prius was designed to utilize the Camry assembly line. Standardization and leveraging of the existing manufacturing process chopped significant time off the product development cycle.

4.3 DFSS: Design for Six Sigma

A fundamental shortcoming of the Six Sigma methodology is that it is designed to improve flawed processes rather than developing superior processes from the start. Six Sigma is reactionary rather than proactive. In the words of Six Sigma expert Subir Chowdhury, "Six Sigma can only take a company so far. To reach the next level, companies need to Design for Six Sigma" (Chowdhury, 2003, 12). While Six Sigma focuses on improving existing designs, DFSS concentrates on creating new and better ones. Quite simply, DFSS is about getting it right the first time.

DFSS expands upon a number of Six Sigma principles and can be implemented within an existing Six Sigma organization or adopted as a stand-alone product development methodology (Ferryanto, 2005, 24). As with Six Sigma, focusing on the customer, identifying needs and expectations are critical components of DFSS. The DMAIC methodology is replaced by a design focused approach. A number of customized acronyms are used by a variety of organizations. Some of the more common of these include ***DMADV*** (Define, Measure, Analyze, Design, Verify), ***DCCDI*** (Define, Customer, Concept, Design, Implement), ***IDOV*** (Identify, Design, Optimize, Validate) and ***DMEDI*** (Define, Measure, Explore, Develop, Implement).

Given the similar nature of these DFSS approaches, it is only necessary to look at one of these in more detail: DMADV, which has a number of parallels with DMAIC (Simon, 2004).

Define the project goals and customer (internal and external) requirements.
Measure and determine customer needs and specifications; benchmark competitors and industry.
Analyze the process options to meet the customer needs.
Design (detailed) the process to meet the customer needs.
Verify the design performance and ability to meet customer needs.

General Electric uses a modified DMADV approach called DMADOV, which includes an Optimize step. These general philosophies are supported with the use of standard design tools such as Failure Modes and Effects Analysis (FMEA), Design of Experiments, and error-proofing among others.

Implementation of DFSS requires a company-wide commitment. A number of subject matter experts are needed, while others within the organization must be familiarized with the concepts. Formal DFSS certification typically requires an intensive two to four week technical training program (Ferryanto, 2005, p. 26). Several DFSS pitfalls can arise. Some of the most severe include a lack of focus or a refocus on cost-savings and the politicization of the process. A successful DFSS implementation requires a long-term vision and a commitment to address customer needs through robust design and process optimization. Such steps encourage continuous improvement in all stages of the product development process.

3M, a company known for its innovation, has adopted DFSS as part of its organic growth strategy and 2x/3x initiative. The 2x/3x process is designed to double the number of new ideas in the commercialization channel and triple the market impact of the resulting new products. To successfully realize such an aggressive goal, a rigorous and systematic framework such as DFSS was needed. At 3M, DFSS is used in conjunction with their stage-gate system. As ideas progress through early gates, a series of tough, DFSS-focused questions are asked. This strategy helps keep projects on track and terminate those that will fail to meet objectives.

4.4 Taguchi Methods

Taguchi Methods, developed by Japanese engineer Genichi Taguchi, are a strategy for quality engineering which focuses on design and the elimination of variation in the manufacturing process. In the words of Taguchi, "Quality is a virtue of design." An inherent lack of robustness in product design is the primary driver of superfluous manufacturing expenses (Taguchi and Clausing, 1990, p. 65). Taguchi's ideas are based on two fundamental tenets (Karbhari, 1994).

1. Quality should be measured by the deviation from a specified target value, rather than by conformance to preset tolerance limits
2. Quality cannot be ensured through inspection and rework, but must be built in through the appropriate design of the process and product

Three concepts develop from these principles: Quality Loss Functions, Off-line Quality Control and Experimental Design.

Rather than accept the premise that the cost of poor quality was just equal to the cost of scrap or rework, Taguchi adopted a much broader cost to society. He identifies three generic situations: the larger the better, the smaller the better and on-target or minimum variation. Next, he assigned Quality Loss Functions to each scenario. In the first two cases, a monotonic loss function is assumed, while in the final case a squared error loss function was created. In a manufacturing environment a specified target is the most prevalent situation. Taguchi's loss function in this case is the same as the statistical concept of total variance. Minimization of this variance is equivalent to the least squares principle. In a manufacturing context, this approach stresses the importance of hitting a specified target rather than just falling within specification limits. Elimination of variation starts with the design process.

Off-line quality control is used to denote the design phase. This nomenclature distinguishes the process from on-line quality control methods, such as statistical process control (SPC), which are reactionary methods. The off-line quality control process has three stages: system design, parameter design and tolerance design. System design is the conceptual framework involving creativity and innovation. Parameter design involves determining the appropriate process and product parameters. Understanding parameter interaction, variation and their impact on performance are key components in robust design. Reducing and controlling variation is an important aspect of tolerance design. The Taguchi method of experimental design is the key tool which is used to determine parameters and tolerances.

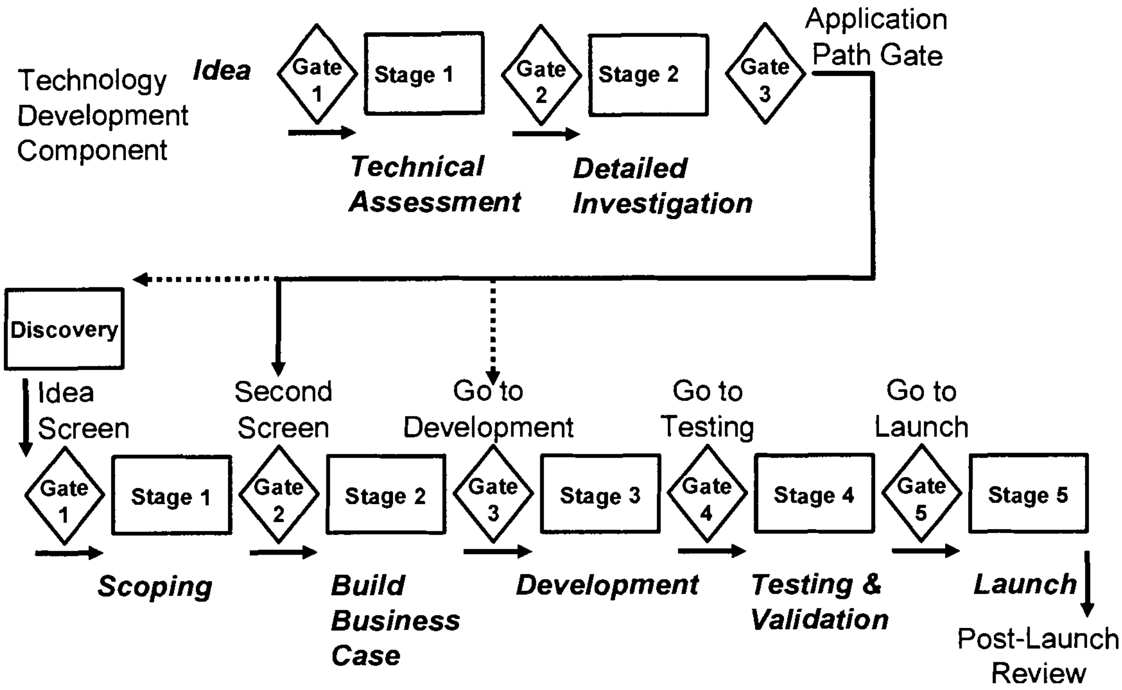
Taguchi's experimental design represents a variation on the traditional Design of Experiments (DOE) approach. The primary difference between the two methods is in how they handle the interactions between inputs. When you keep in mind that DOE was invented by scientists for scientists, and Taguchi Methods were invented by engineers for engineers, the differences begin to make sense (Cesarone, 2001, p. 37). Rather than testing all combinations of inputs, as in a full factorial DOE, Taguchi analysis looks at only a small subset. The experimental layout in a Taguchi experiment is strictly regimented, but these details can be found in a number of texts on the subject.

The key point to remember when applying Taguchi Methods to new product development is to minimize variation primarily in the design phase. Fortunately, there are a number of parallels between designing for robustness and designing for manufacturability. Similarly, a robust process is one that is most likely to deliver goods which satisfy customer requirements.

4.5 Stage-Gate

Stage-Gate is a trademarked new product development process created in the mid 80's by Professor Robert Cooper at McMaster University. According to the Product Development Institute, 73% of North American companies have now adopted a Stage-Gate process for their new product development. Stage-Gate provides a methodical process by which to advance a company's new product development. Figure 4 depicts the standard five step Stage-Gate process as well as the enhanced technology discovery component. A more detailed discovery process was identified as major refinement opportunity to the nearly 20 year old Stage-Gate methodology.

Figure 4. The standard 5 step Stage-Gate process coupled with the Technology Development process



Source: author based on Cooper et al, 2002

The Stage-Gate model applies to both individual projects as well as the company's entire project portfolio. Consequently, the evaluation process and structure must be formalized. This is typically the responsibility of senior management. Since Stage-Gate has been implemented across numerous organizations and has existed for some time, the original creators of the process have had the opportunity to reflect upon and refine the methodology. Cooper, Edgett and Kleinschmidt identify three main areas for improvement (Cooper et al, 2002a, p. 21).

1. Adding a Discovery stage at the front end of the process to generate breakthrough product ideas.
2. Harnessing fundamental research more effectively.
3. Improving project selection and becoming more discriminating in the projects undertaken- incorporating more effective gates.

Idea generation, the discovery phase, is critical to new product development. Several refinements have been suggested to improve this process, including filtering all ideas into a focal point or new product process manager. Idea generation is recognized as originating from two primary sources: the customer and the entire organization. Adopting a Voice of the Customer approach and working closely with lead customers can lead to innovative new products. Companies such as Hewlett-Packard and Fluke use this approach and have entitled it "camping out" with the customer. Harnessing the creative potential of the entire organization can occur through both informal and formal routes. An informal mechanism should be in place to encourage all employees to bring forward ideas. Ideas that pass the initial screen should be paired with the appropriate resources and a project champion to guide the concept through the subsequent stages. A formal idea generation event can consist of a multi-day off-site conference with the intention of identifying major revenue generating opportunities. The goal of this meeting is to identify the major trends, shifts, changing customer needs and potential disruptions taking place in the marketplace (Cooper et al, 2002a, p. 25).

Although in recent years numerous companies have been scaling back their fundamental research, such activity can play an importance roll in idea generation and ultimately product commercialization. The Stage-Gate process for Technology

Development, which is illustrated in the top half of Figure 4, attempts to address the criticism that basic research is undirected, unfocused and unproductive. The gates in the technical assessment and investigation phase are much more strategic in nature as compared to the financial focus of the standard Stage-Gate process. Assessment includes the degree of strategic fit, leverage, as well as the likelihood of technical and commercial success. Once a project has cleared the final gate in the technology development phase, it can enter the new product development Stage-Gate at any of the first three gates. Most projects will typically enter at the second gate.

Within the standard Stage-Gate framework, it is necessary to implement effective gates in order to properly assign scarce resources within the company. Most companies have trouble killing projects or pruning the new-product portfolio (Cooper et al, 2002b, p. 43). The project gates must be used as real Go/Kill decision points rather than merely project review points. This is most applicable in large companies with large project portfolios. Standardization of the evaluation process is key in creating fair, efficient and effective decisions. A project evaluation scorecard should be created which contains both "must meet" and "should meet" criteria. Suggested evaluation criteria include: strategic, product advantage, market attractiveness, synergies, technical feasibility and risk versus return (Cooper et al, 2002b, p. 46).

Adaptation of the Stage-Gate process to fit specific circumstances is common. Most often this is based on project risk. One variation is the SCR Process which handles Significant Customer Requests. In this case, the process is condensed into just two gates (an initial screen and a decision based on the business case) and two stages (an analysis of the business and a development and implementation phase). Another variant is the

Fast Track Project which is designed for lower-risk projects. In this three phase case, stages one and two are combined as well as stages three and four.

Although Stage-Gate can provide the generic framework to guide a company's product development strategy, one should customize the process to match the organization's structure, resources and objectives. The incorporation of other product development best practices can be included as part of the customization process. Understanding the typical pitfalls of this methodology also helps a company utilize this process more effectively.

5 ANALYSIS OF OPERATIONS AND ENGINEERING AT CREO

This investigation of applying lean principles to product development now moves from a conceptual overview to the more specific tasks of application and implementation. This section serves as the transition between general theory and specific application by examining circumstances pertaining to Creo. The methodology used in this section is to dig down from the external image, presented in annual reports and press releases, to the internal realities of the organization obtained through internal documents, procedures and interviews with employees.

5.1 Analysis of Operations

As noted earlier in section 2.1, Creo's operations focus on digital pre-press systems including software, proofing, input and output systems. Creo also places a significant emphasis on research and development. This activity has generated a sizeable intellectual property portfolio. Both manufacturing and new product development play important roles in Creo's success. Operational improvements are already underway at Creo. The 2004 annual report recognized that in order to achieve its top priority of delivering earnings growth, Creo needed to target "efficiency improvement programs to reduce service and equipment manufacturing cost of sales" (Creo, 2005, p. 21). These initiatives began in the fiscal fourth quarter of 2004 (third quarter of the calendar year) and were targeted to realize $24 million in annualized savings (Creo, 2005, p. 67). Although the subsequent acquisition by Kodak has created a period of transition, the overall objective of recognizing cost-savings through increased efficiency remains the same. The application of LM principles can now be augmented with the implementation of KOS to achieve productivity gains beyond manufacturing and throughout the organization, especially in product development.

Analysis of inventory levels can provide valuable insight into the effectiveness of a company's resource management. Table 5 examines Creo's inventory levels over the past three years. Inventory is classified within three categories: Equipment, Service Materials and Consumables. A further dissection into standard inventory sub-classifications is also provided.

Table 5. Analysis of Inventory Levels and Trends at Creo

INVENTORY

dollar figures in thousands	2004		2003		2002	
Equipment	**61,962**		**58,629**		**60,214**	
Materials		27,963		21,796		24,247
Work-in-progress		12,131		14,739		12,051
Finished goods		21,868		22,094		23,916
Service materials	**27,105**		**31,755**		**27,247**	
Consumables	**22,678**		**6,061**		**4,338**	
Materials		5,029				
Work-in-progress		2,108				
Finished goods		15,541		6,061		4,338
Total Inventory	**111,745**		**96,445**		**91,799**	

REVENUE

dollar figures in thousands	2004	2003	2002
Equipment	379,489	360,618	336,329
Service materials	179,520	170,104	158,586
Consumables	76,790	47,316	44,537
Total Revenue	635,799	578,038	539,452

Inventory as a percent of revenue

	2004	2003	2002
Equipment	16.3%	16.3%	17.9%
Service materials	15.1%	18.7%	17.2%
Consumables	29.5%	12.8%	9.7%
Total	17.6%	16.7%	17.0%

Data Source: Creo Annual Report

The most illuminating insight is gained by examining inventory levels as a percentage of revenue within each business segment. Manufacturing inventories, represented under the equipment category, show a slow improvement. This is likely attributable to the initial efforts to implement LM. The most notable figure is the dramatic rise in consumables inventory. This can be explained by Creo's decision to become a provider of digital plates. As a supplier of consumables, Creo must exhibit a leaner operation and management of the distribution network. However, this fact may be moot given Kodak's decisions regarding Creo's plate business.

An alternative perspective on Creo's inventory management can be gained by examining inventory turns. Table 6 provides both trend information for the past three fiscal years and a direct comparison to Kodak for the 2004 fiscal years.

Table 6. A Comparison of Inventory Turns between Creo and Kodak

Inventory Turns: COGS/Inventory

dollar figures in millions

	Creo			Kodak
	2004	2003	2002	2004
Revenue	636	578	539	13517
COGS	366	320	307	9548
Inventory	112	96	92	1488
Inventory Turns	3.28	3.32	3.34	6.42

Data Source: Creo and Kodak Annual Reports

Creo's inventory turns are trending downwards- heading in the wrong direction. This is most likely influenced by the increase of consumables inventory which has offset any gains in manufacturing. Additionally, Creo's inventory management is significantly worse than Kodak's. The fact that Kodak also generates a large portion of its revenue from its consumables (film) business, suggests that Creo should adopt some of Kodak's best practices regarding inventory management. Reducing inventory, increasing inventory turns, is beneficial for a number of reasons: it frees up cash resources, reduces holding costs and reduces the risk of inventory becoming obsolete.

Although the concepts of inventory and inventory turns are less applicable to the product development process, the underlying message is not. The product development process must be more efficient in its use of resources. Best practices have a tendency to diffuse through an organization. Consequently, a company demonstrating lean practices in its manufacturing and resource management is more likely to be utilizing lean principles in its product development.

5.2 The Matrix Organization

Within Engineering, Creo organizes itself along project-lines with functional capacities identified within each project. These project groups are headed by either product or project managers. In general, the organization is relatively flat which is consistent with Creo's philosophy of self-empowerment. Such an organizational structure conforms to what is known as a "heavyweight team structure" (Clark and Wheelwright, 1992, p. 13). Since work is organized around projects, it is necessary to coordinate employee assignments at the beginning and end of the project. A variety of functional pools exist within the company; these include electrical, mechanical and optical engineering as well as firmware and software design. Supporting roles such as technicians, layout and documentation are also drawn from functional pools.

There are both positives and negatives associated with the matrix-like organization. A primary benefit is that resource allocation is flexible and can adapt to the complexities and uncertainty of the environment (Nohria, 1995, p. 1). This structure also enables employees to develop strong functional competencies while still gaining the experience of working on a variety of projects. In order to avoid the dual reporting structure that can plague a true matrix organization, Creo relies on section heads rather than functional managers. One of the primary responsibilities of these individuals is mentoring junior employees. Similarly, a strong team-based environment helps foster knowledge transfer and group learning. A drawback of such an organizational structure is the limited number of truly heavyweight managers. Creo's approach to this problem is to utilize both project managers and project engineers. Finally, the resource allocation question arises: Is this system effectively leveraging the knowledge of the functional subgroups?

5.3 Stage-Gate at Creo

Creo uses a Stage-Gate like process known as the Product Development System (PDS). This system is designed to serve as the framework for all new product development and major revisions to existing products. Given that a sizable fraction of North American firms are using a stage-gate process for their product development activities, it becomes highly debatable whether or not such an activity actually provides a significant competitive advantage to the individual organization. Taken to the extreme, the generic application of a stage-gate system may lead to mediocrity in a company's new product development process.

PDS is a linear process which maps a product from the idea phase to end-of-life. Each step of the product life-cycle contains a number of key activities and deliverables. These project steps are separated by series of milestones and governed by a number of project review points. PDS is a structured process which is designed to create efficiency through the use of a series of templates. Projects are guided by Project and Product Managers, and reviewed by the Global Product Steering (GPS) committee. Although PDS is intended as a guideline and not a standard, it is a very thorough, regimented process. At its worst, the system could break down into a checklist-based activity. Additionally, PDS is subject to the same criticisms that the original Stage-Gate creators observed in their detailed review of Stage-Gate users. Most notably, PDS milestones and the review process do not serve as strict gates by which to evaluate and potentially terminate projects.

Killing projects is certainly one of the most difficult aspects of the new product development process. As projects progress, considerable time and resources become committed to the project. As difficult as it may be, these costs should be treated as sunk costs and should not factor into decisions about future resource use. However, this approach is most applicable to companies which have large project portfolios. This strategy is not realistic for smaller firms or for projects on which the company has "bet the business." Despite its rank as one of BC's largest technology-focused companies (Business in Vancouver, 2005, p. 54), Creo does not have a large project portfolio. This reality suggests that Creo's product development process must contain an excellent initial screen process. Under this scheme, a milestone and checklist approach is appropriate. Hence, one must ask the question "Is the front-end of PDS effective?"

Creo has a generally good record with regard to idea generation. This is evidenced by the company's strong intellectual property portfolio and its patent generation rate as discussed in section 2.1. However, the conversion rate on these ideas could be improved upon. In its over 20 year existence, Creo has not generated any spin-off companies. Apart from the transition from optical data storage to digital pre-press systems in the early 90's, Creo has not created any new business units outside of this core focus. Creo has entered into a number of strategic partnerships, joint develop activities and licensing agreements in order to take advantage of its innovation. Granted, such a strategy enables the company to focus on its core segment and minimize or share product development risk. All of these points bring to mind the following question: "Is PDS effectively capitalizing on ideas?" In short, the answer is "no". Alternatives to rectify this situation will be proposed in chapter 6.

Another criticism of PDS relates to the process cycle time. In any process methodology, reducing development time is beneficial: effectively making the system leaner. A major source of added cycle time is "hand-offs". Ineffective hand-offs from development to manufacturing can result in significant project delays and considerable rework. This creates duplication of effort and is an inefficient use of resources. This issue will also be addressed in chapter 6.

In this chapter, we have seen that there is both a clear need and benefit in implementing lean practices throughout the organization. In Creo's Engineering department, the flexible matrix-like hierarchy could facilitate the TPDS system used at Toyota or continue with a variation on the existing PDS strategy. Since we now have an understanding of Creo's existing product development methodology, we can begin to examine other possibilities.

6 ALTERNATIVES AND APPLICATION OF BEST PRACTICES TO PRODUCT DEVELOPMENT AT CREO

With a solid understanding of both new product development methodologies and Creo's organization, we can start to investigate the application and integration of these practices. Creo's existing Product Development System (PDS) has delivered adequate results so far, but improvements to the system are certainly possible. The subsequent analysis will attempt to determine if minor tweaks or radical adjustments are required.

Since continuous improvement, or *kaizen*, is a fundamental tenet of Lean principles, it is only appropriate that the product development process be subject to a *kaizen* event. Furthermore, the new ideas and organizational change which occurs following an acquisition suggests that now is an appropriate time to modify the product development process. There is however a delicate balance between harnessing the winds of change and over-stressing the system to create turbulence and chaos.

Clearly, one cannot expect that the haphazard application of a generic product development scheme will deliver superior results for the firm. The customization process is not easy, yet it can be a source of competitive advantage for the firm. The appropriate methodology must be tailored to the organization, its resources and its goals. The relevancy of the process to the organization is a critical factor in its ultimate success. Similarly, change within an organization is the impetus for productivity gains yet it can also serve as a disruptive force. An understanding of the existing organization serves as the basis from which to assess both the magnitude and impact of the proposed change. Resistance to change, or alternatively, the ease with which a change can be implemented impact the transition process and the end result. This challenge manifests itself as yet another form of a risk/reward analysis. Hence, the net benefit or rewards associated with the change are closely tied to the implementation risk.

The remainder of this section will examine three alternatives: modified Stage-Gate (or modified PDS), TPDS, and a hybrid approach. These methodologies will be evaluated against three over-arching criteria: relevancy to the organization, ease of implementation and impact. Each of these criteria contains more direct measures such as the impact on competitiveness, manufacturability, quality, knowledge generation and earnings growth. The sections will begin by examining the relevancy of the methodology to Creo's organization and investigates what the system would look like. This will be followed by a discussion on the implementation and conclude with an assessment of the impact.

6.1 Modified Stage-Gate

Section 5.3 already examined the strengths and weaknesses of Creo's existing PDS process. The main benefit of this system is that it provides a thorough, structured process by which projects can be guided. However, the system can breakdown into a series of checklists, fail to optimize resources and delay product release due to awkward transitions to manufacturing. Additionally, since PDS is more of a guideline rather than a standard, it has not been rigorously followed which has created a schism between theory and practice. Almost by default, we can assign a high relevancy of this existing system to

Creo's operations. However, we must also acknowledge that limited deviations from this system will offer only marginal gains and a limited ability to differentiate Creo from the competition.

The challenge is not with maintaining the status quo, but with identifying and implementing the appropriate changes to improve upon PDS. In the simplest of terms, PDS must be made leaner. Since this alternative represents moderate rather than radical change, a modified PDS should concentrate on the following three issues:

1. Greater adherence to the process standards.
2. Reducing cycle-time by minimizing hand-offs.
3. Improving the front-end of PDS.

There is a delicate balance between structure and flexibility in any product development methodology. However, by creating a "living" process with defined, yet continually refined, procedures, a new organizational mindset will be adopted. In order to realize the benefits of PDS, the entire organization must believe in, and adhere to, the system. The system is changeable, but people must work within the system. Clearly defining expectations and adhering to protocols must be two requirements of a modified PDS. Defining expectations means asking the tough questions relating to product cost and profitability, reliability, serviceability, and technical specifications.

Through both standardization and a focus on manufacturability, Creo can reduce the delays caused by re-engineering processes. During design and development, manufacturing must be involved. This can be achieved with either direct participation from manufacturing or by ensuring that the development team has experience with manufacturing processes. Ideally, as part of the career development process, all members of the team should have job rotations in manufacturing operations. Additionally, team leaders must assume a great deal of responsibility for the process. These individuals must have a solid understanding of manufacturing, business objectives, and the project's goals.

The overall objectives and stage-based objectives can be made clearer by improving the front-end of the process. While the design phase must still focus on customer requirements, manufacturability, quality, and profitability, it is too early to formally commit to a product deliverable date. Understandably, sales and being first to market are strong business forces which pressure product development. Although such factors exist in many industries, there is a strong system lock-in effect in the pre-press industry which makes being first to market even more important to overall success. The pre-development phase needs to be separate from the commercialization phase. Projects in the pre-commercialization phase should be overseen by a technology gate keeper. Although these projects are still subject to deliverables and deadlines, they are buffered from market forces.

Implementation should be made easier since these proposals represent modifications to the existing system. Educating employees about the changes and the rationale behind them are critical elements in facilitating the transition. Thus, the challenges associated with implementation are moderate and the impact of these changes will also be moderate. The goal is to achieve incremental improvement rather than radical change. The modified PDS should have a direct impact on manufacturability and competitiveness. In turn, there should be a positive impact on earnings growth, quality and knowledge transfer.

6.2 TPDS at Creo

The fundamental question that must be raised is: Can TPDS be implemented successfully outside of Toyota? Arguably, a similar question was asked several decades ago regarding TPS. The popularity of Lean Manufacturing has answered that question with an emphatic "yes". However, this leaves us to ponder why Toyota would give away the source of its competitive advantage. Two possible explanations are that their competitors lack the flexibility and organizational culture needed to successfully implement the system. Rigid union contracts hamper the integrative social processes which are critical to TPDS. Additionally, the high barriers to entry in automobile manufacturing prevent new competition. While these factors may hinder the adoption of TPDS in the automotive sector, they do not preclude the successful implementation in other industries.

The more directly applicable question is: Can TPDS be implemented successfully at Creo? Creo's organizational culture and flexibility suggests that a TPDS-like system is possible. Furthermore, the standardization aspects of TPDS are less company specific and therefore can be applied to different settings. The remaining issue is the relevancy of TPDS to Creo's product development. Competitive tear-downs, a regular occurrence at

Toyota, are generally not applicable to Creo. Similarly, does a company need to exceed a critical size in order to develop functional excellence in specialized tasks? Or are a minimum number of projects required per year in order to facilitate continuous learning? The fact that twenty years ago Toyota was manufacturing cars, and Creo wasn't manufacturing digital pre-press technology, provides some inherent advantages for Toyota. Some consequences for Creo are that chief engineers are in limited supply, process standards are less refined and there is less overlap in product cycles. Given the limitations of a full TPDS, a modified version is therefore suggested and outlined below. In summary, the relevancy or fit of TPDS at Creo is moderate.

TPDS at Creo would follow the same structure as at Toyota and outlined in figure 3. Customer focus is supported by the integrative social processes and standardization. Of these two pillars, the greater challenge to Creo is standardization given the greater diversity of projects as compared to Toyota. Developing design standards around critical processes or core components is one step towards standardization. The objective is to reduce the amount of re-engineering and therefore improve productivity. Once standards or design checklists are in place for Creo's core components, generalized design checklists can be created as templates for new components and processes. The development of standard skills already exists at Creo through mentoring and team-based projects. This TPDS component has a strong link to the organizational culture. Creo's leadership and engineering has many common threads with Toyota, most notably having engineers in prominent positions within the company.

Implementation of a modified TPDS, again has a strong dependence on standardization. It also represents an easier and more suitable task than trying to replicate

TPDS in its entirety. Thus, implementation ranks as moderate to difficult. Communication is not only an important element within TPDS, but also during its implementation. An understanding of the system and its goals are important on both the global level and at the project level. A modified TPDS reduces some of the implementation risk, but also reduces the impact.

6.3 A Hybrid Approach

Conceptually, a hybrid approach seems to address the limitations of both PDS and TPDS while incorporating their benefits. The challenge is to determine what such a hybrid system looks like. It can certainly be built upon a PDS framework, while incorporating the standardization aspects of TPDS. Standardization and customer focus are elements common to other development methodologies such as DFSS. Another critical element is the emphasis on the ***Definition*** phase of the project. Clear definition and communication of objectives requires a rigorous adherence to the methodology, but helps prevent confusion later in the process. A further challenge is retaining enough flexibility to keep design options open as late as possible.

Implementation of such a strategy should be incremental. Modifications to the existing PDS would be followed by the incorporation of TPDS practices. A gradual roll-out is consistent with a continuous improvement mindset and it maximizes the likelihood of acceptance. A consequence of the reduced risk is that the benefits are delayed. The implementation schedule serves as a tool with which to balance risk and reward.

6.4 Summary of Alternatives

This section provides both a comparison and summary of the product development options. Table 7 provide a matrix representation of the three alternatives ranked according to the three main evaluation criteria.

Table 7. Summary and Ranking of Product Development Alternatives

	Modified Stage-Gate	**TPDS**	**Hybrid System**
Relevancy	High	Moderate	High
Implementation	Moderate	Difficult-moderate	Moderate
Impact	Moderate	High	High

Although one could assign relative weights to the evaluation criteria and quantify this process, it would produce an artificial best choice. A clear solution does not exist. Rather, an incremental, yet continuous, process can be used to achieve superior results. Best practices exist in each of these alternatives. However, one must then ask: Is it possible to achieve a coherent system by selectively picking key aspects from a variety of methodologies? Given that a number of common threads exist between differing product development methodologies, I believe that it is possible to mix methodologies and customize these tools to create a company-specific application. This is attempted in the following chapter.

7 RECOMMENDATIONS

Unlike the majority of North American companies, Creo has a strong corporate culture and an industry leading position upon which to build. This represents a fertile environment in which to implement key elements of a lean product development strategy such as TPDS with its strong social and culture component. Strong similarities exist between the different methodologies and certain best practices in product development are almost self-evident. No company will claim to lack a customer focus or be disinterested in quality. However, focusing on the needs of the customer and product manufacturability during the design and development phase is much more subtle.

In Chapter 6, three alternatives were presented. In addition to examining the critical issues associated with each option, a discussion detailing what the system would look like was offered. From this investigation, no one strategy emerged as the clear choice; however, recurring themes did materialize. This insight forms the basis for following core recommendations regarding the application of lean principles to the product development process. They are presented below in order of importance.

1. **<u>Standardization of Processes</u>** – Standardization forms the foundation of lean manufacturing and lean product development. It is a driving force for productivity gains through cycle time reduction and the elimination of waste. To achieve results from the product development process, Creo must create a more

formalized system rather than a set of guidelines. Adherence to the system is the best way to integrate it into the company's culture.

2. **Continuous Improvement** – Although the creation of standard protocols may remove flexibility from the process, this does not need to be the case. These standards should be considered living documents that are continuously updated to reflect the latest best practices. Following the completion of projects, *Project Post-Mortems* should be conducted to determine both successes and failures. This knowledge generating exercise must become a required part of the product development system.

3. **Design for Manufacturability and Quality** – These are not inherent mandates of the Stage-Gate process, yet they need to be included as part of a lean product development strategy. Manufacturability includes not only the technical or engineering concepts, but also the business requirements such as profitability and deliverability. Involvement of the manufacturing organization in the design and prototyping phases of product development can help achieve this goal. Additionally, design team members should maintain a close relationship with manufacturing, including spending time on the shop-floor, and keeping abreast of the latest practices.

4. **Separation of Pre-Development from Commercialization** – Although profitability and customer-focus must remain primary objectives during the pre-development phase, this stage of the process should be unencumbered by the constraint of a firm customer deliverable date. Firm commitments short-circuit

the design and exploration phase and can result in the abandonment of the "design for manufacturability and quality" objective. The goal during this phase is to minimize the technological and business risks.

5. **Definition and Communication of Objectives** – This requirement is closely related to the primary recommendation of process standardization. The definition and communication of project objectives must be identified early in the project. This practice helps create congruent goals amongst different functions within the organization. Although objectives can change during the development process, such events need to be formalized and communicated to the team members and other effected parties.

6. **A Learning-Focused Organization** – Creo's culture already encourages the sharing of knowledge through team-based activities and mentoring. This practice can be further enhanced by recognizing the importance of creating and formalizing new processes in conjunction with the creation of new products. In order to see increased future returns on the product development process, best practices, in addition to products, must be recognized as valuable outputs from the system. As recommended earlier, these practices need to become part of the standard product development process.

7. **Flexibility** - Although flexibility appears to be in direct conflict with standardization, these two concepts co-exist within a lean manufacturing environment and can do so within a lean product development system. It is important to recognize that different projects will have differing requirements.

The system must have the flexibility to address this. An example of contrasting needs would be a product update versus the commercialization of a new idea. In the case of the former, a considerable amount of expertise will exist within the company. For the latter, this knowledge will be harder to come by.

What has been presented here is not a quick-fix, but rather a slow, methodical approach to realizing greater value from the product development process. Although a list of recommendations makes the course of action appear straight-forward, implementation is not easy. Creo is prepared to face these challenges, but the organization must also push itself to create its own unique processes. The company cannot be satisfied with an "as good as" mentality that can result from benchmarking, it must strive for superior performance.

APPENDICES

Appendix A. Creo- 3 Year Statement of Operations

(in thousands of United States dollars, except share and per share data, and in accordance with Canadian GAAP)

Years ended September 30	2004	2003	2002	2003 to 2004	2002 to 2003
Revenue:					
Product revenue	$ **379,489**	$ 360,618	$ 336,329	5.2%	7.2%
Service revenue	**179,520**	170,104	158,986	5.5%	7.0%
Consumables revenue	**76,790**	47,316	44,537	62.3%	6.2%
Total Revenue	**635,799**	578,038	539,852	10.0%	7.1%
Cost of Goods Sold	**366,180**	320,197	306,581	14.4%	4.4%
Gross profit	**269,619**	257,841	233,271	4.6%	10.5%
Gross Profit Margin (%)	**42.4%**	**44.6%**	**43.2%**	-4.9%	3.2%
Research and development, net	**84,464**	79,007	73,378	6.9%	7.7%
Sales and marketing	**112,763**	106,892	97,893	5.5%	9.2%
General and administration	**62,459**	63,767	67,259	-2.1%	-5.2%
Other expense (income)	**-913**	-7,997	-5,397		
Business integration costs and restructuring	**4,336**	3,423	9,140		
Goodwill and other intangible asset amortization	**3,148**	2,659	309		
Royalty arrangement	—	—	15,530		
Total Expenses	**266,257**	247,751	258,112	7.5%	-4.0%
Earnings (loss) before undernoted items	**3,362**	10,090	-24,841		
Gain on sale of investment	**8,723**	—	—		
Income tax (expense) recovery	**-611**	-1,541	2,680		
Equity loss	—	-3,040	-2,141		
Minority interest	—	—	—		
Net earnings (loss)	$ **11,474**	$ 5,509	$ -24,302		
Net Profit Margin (%)	**1.8%**	**1.0%**	**-4.5%**		
Basic earnings (loss) per share	$ **0.22**	$ 0.11	$ -0.49		
Diluted earnings (loss) per share	$ **0.21**	$ 0.11	$ -0.49		
Shares used in per share calculation:					
Basic	**52,765**	49,788	49,528		
Diluted	**53,573**	50,520	49,528		

Appendix B. Kodak- 3 Year Statement of Operations

(in millions, except per share data)		2004		2003 (Restated)		2002	2003 to 2004	2002 to 2003
		For the Year Ended December 31,						
Total Revenue	$	**13,517**	$	12,909	$	12,549	4.7%	2.9%
Cost of Goods Sold		**9,548**		8,734		8,022	9.3%	8.9%
Gross profit		**3,969**		4,175		4,527	-4.9%	-7.8%
Gross Profit Margin (%)		**29.4%**		32.3%		36.1%	-9.2%	-10.3%
Selling, general and administrative expenses		**2,507**		2,618		2,504	-4.2%	4.6%
Research and development costs		**854**		776		757	10.1%	2.5%
Restructuring costs and other		**695**		479		98		
(Losses) earnings from continuing operations before interest, other income (charges), net and income taxes		**-87**		302		1,168		
Interest expense		**168**		147		173		
Other income (charges), net		**161**		-51		-101		
(Loss) earnings from continuing operations before income taxes		**-94**		104		894		
(Benefit) provision for income taxes		**-175**		-85		133		
Earnings from continuing operations	$	**81**	$	189	$	761	-57.1%	-75.2%
Earnings from discontinued operations, net of income taxes	$	**475**	$	64	$	9		
NET EARNINGS	$	**556**	$	253	$	770	119.8%	-67.1%
Net Profit Margin (%)		**4.1%**		2.0%		6.1%		
Basic net earnings per share:								
Continuing operations	$	**0.28**	$	0.66	$	2.61		
Discontinued operations		**1.66**		0.22		0.03		
Total	$	**1.94**	$	0.88	$	2.64		
Diluted net earnings per share:								
Continuing operations	$	**0.28**	$	0.66	$	2.61		
Discontinued operations		**1.66**		0.22		0.03		
Total	$	**1.94**	$	0.88	$	2.64		
Cash dividends per share	$	**0.5**	$	1.15	$	1.8		

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