Transforming Commercial Aerospace Supply Chain Management Practices by Utilizing Toyota Production System Principles, Practices, and Methodologies

By Steven M. Patneaude

M.S. Project Management
The George Washington University, 2002

SUBMITTED TO THE SYSTEM DESIGN AND MANAGEMENT PROGRAM
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN ENGINEERING AND MANAGEMENT

AT THE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JANUARY 2008
[February 2008]

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ABSTRACT

This thesis examines The Toyota Motor Corporation's core precepts, management principles, supply chain architecture, product development methods, leveraged practice of supplier partnerships and procurement practices, all of which are integral elements associated with the Toyota Production System, and assesses the scalability these elements for application in the commercial aerospace industry.

The methodology used in this study includes an examination of basic concepts and practices that Toyota employs throughout its extended enterprise and which are being widely adopted throughout the automotive industry as well as other industries worldwide, based on a review of the open literature. The research also draws upon the author's first-hand exposure to Toyota's production system through field research involving benchmarking site-visits to Toyota plants, and makes use of extensive interviews conducted with both automotive and aerospace industry experts.

The research reported in this thesis reveals that Toyota's Production System, as a mutually reinforcing set of principles, methods and practices, are indeed scalable to the aerospace industry and that one of the two commercial aerospace behemoths, Boeing and Airbus, has an opportunity to leverage them in order to obtain a clear and sustainable competitive advantage in the industry. This is possible, however, with an important caveat: the end-to-end enterprise transformation process would need to be based on adopting a long-term approach to renovating the current system, working closely with the supply chain partners, owning the change process, and holding steady over the longer-haul.

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ACKNOWLEDGEMENTS

Writing this thesis has been one of the biggest challenges in my life, but also has been one of the most gratifying experiences I have ever personally achieved. My journey at the Massachusetts Institute of Technology, participating in the System Design for Management (SDM) Program, has been an extremely long road, which has included many long nights, trips away from my family, and a stretching of my mental capacity beyond what I often thought possible. I am grateful for this wonderful opportunity and will always hold this time in my life as a period of enlightenment and great enrichment. I would briefly like to thank the following people, without whom I do not believe this opportunity would have been possible.

First, I would like to thank my family, which has provided me a foundation to live by and a core set of beliefs that drive me every day to strive to be the best I can be in everything I do. For this, I thank my parents, Michael Patneaude and Suzanne Cowles. My Dad has always been my hero and my Mom has always been the warm and loving spirit of our family. I also owe long overdue thanks to Sue Patneaude for her guidance while I was in high-school; thank goodness, you pushed me to hit the books and had me look beyond what sports could offer me. I also need to recognize my sister Beth and brother-in-law Tom: I will always and forever consider the two of you my guardian angels who helped me through one of the toughest times in my life. To my brother Joe, you will always be the brother I look up to and admire, and to my youngest sister Danielle, I hope all your dreams come true, we all know you have one of the most gifted minds in our family. A couple of more quick points to reinforce my thanks; to Pat Walsh, thank you for your bond with the kids and giving Erin and I the opportunity to swim to the surface and breathe every once and a while during this journey, to the Patneaude Family for everything and especially for the great times we have every year at Spectacle, and to my Grandma – Florence Patneaude, the bravest woman I know and respect.

Professionally, I owe a debt of gratitude to Mike Herscher, my Boeing sponsor who ensured that my participation in the SDM Program was done right. I am honored to have learned from you and will always appreciate the fact that you taught me the importance of wearing my jeans, rolling up my sleeves, and getting my hands dirty on the gemba. I also owe many thanks to Leonard Hoch, one of the greatest business minds I know, and to Ren Nanstad for the opportunity to support our BCA Transformation efforts -- you both are great teachers and thinkers, and I have immensely benefited from learning from the two of you. Lastly, I would like to thank Gil Duncan and Justin Franke -- the two of you took me under your wings during a pretty difficult time in my life professionally. The due diligence and guidance both of you offered during these hard times will never be forgotten; you are both great leaders and I hope to make the two of you proud.

From the SDM Program, I would like to thank Pat Hale for the opportunity to participate in the program. Without Pat's support, leadership, and guidance I am not certain I would have followed-through and applied to the program. To Helen Trimble, thank you for your hospitality during our semester business trips, a bright face and warm smile are always nice and comforting to come across when being away from family and friends.

Academically, I would like to thank Kirkor Bozdogan. Kirk, thanks for your guidance, flexibility, and support with this thesis, without your supervision I am not sure I would have made it.

Furthermore, I also owe a great deal of gratitude and need to thank my children Brayden, Andrew and Ella. I know that it is not easy having a Dad who works what seems to be all the time, travels, and always is doing homework when fun activities have passed us by. I hope all three of you know how proud you make me. It's time we start spending our time together and that we enjoy the time we have together before you have all grown and spread your wings. In the last three years each of you have grown so much -- I fully understand we only get one shot and I would hate to look back and have any regrets. All my love my beautiful children!

Lastly and certainly most importantly, to my wife Erin, L'amor de la mia vita; you are my rock and without you by my side, these last three years would absolutely not have been possible. Thank you for giving me a shoulder to lean on and cry on when I thought I just could not do it anymore. While you are the absolute love of my life, you have also more than proven yourself to be the foundation and cornerstone of our family. I love you with all my heart and hope I have made you proud; you should enjoy this achievement every bit as much as I do.

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This thesis is dedicated to the memory of Robert Michael Patneaude.
Big brother, I wish I could have gotten to know you better.
We lost you too early.

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1 THESIS ARGUMENT

In today's marketplace, Airbus and Boeing dominate the commercial aircraft industry creating a duopoly for single aisle, twin aisle, and large airplanes. As it has already been well documented, both airplane manufacturers have been engaged in cut-throat competition in recent years, with each company laying claim to greater annual market share, hedging bets in the form of discounted large block order sales, offering mass customization to deliver high-end leading edge interior packages to peak the interests and suit the demanding needs of first-class and business-class travelers, and developing innovative new products to secure a larger share of the global market in the future. This competition has produced, in most recent years, the world's largest commercial aircraft (Airbus A380) and the first all carbon fiber aircraft predicted to optimize fuel consumption by 20% (Boeing 787). It has also set in motion plans for the projected development of the first aluminum framed all carbon fiber paneled airplane (Airbus A350-XWB).

This bitter competition is expected to continue and even intensify in future years with both companies vying for annual market positioning, against the backdrop of a robust twenty-year commercial airplane market forecast which projects that 28,600 aircraft worth a staggering $2.8 trillion will be delivered before the year 2026 (Source: www.boeing.com, Twenty Year Market Forecast). If this market prediction holds true, it would mean that Airbus and Boeing would both have the prospect of having to achieve peak production performance annually for over twenty years, turning over the world fleet of aircraft by almost 80% (Source: www.boeing.com, Twenty Year Market Forecast). This represents an absolutely staggering statistic considering that the sustaining and development programs both companies will be waging against one another will continue to be heavily dependent on participation from globally sourced suppliers. In fact, both companies have disclosed that they are already sourcing nearly 70% of the hardware and systems that comprise their product designs. As such, while Airbus and Boeing dual with each other for market dominance in responding to the unprecedented projected growth in the marketplace, their global network of suppliers face serious capacity as well as capability constraints. These constraints will reverberate right up through the upstream industries providing the needed raw materials and commodities for which there is likely to be increased worldwide competition in the future. The supplier networks are further challenged with doing more technical design work to support system-of-systems product integration.

With both Airbus and Boeing operating with very traditional supply chain management practices that account for roughly seventy to eighty percent of their fixed cost base, the basic question facing both manufacturers should not be focused solely or mainly on their annual market share performance. Rather, their central focus should be fixed on the longer-term strategic, tactical and incremental steps they will need to take to implement proven world-class supply chain management practices. They must ensure the development of supply chain management practices that will enhance holistic system performance throughout the extended enterprise. This means a supplier network consistently and reliably delivering improved quality, ensuring the required velocity of output, and exhibiting sustainable predictability. Having sustainable predictability enables stability in the performance of daily operations and product design activities. It is also essential for supporting the very aggressive projected production targets to meet the growing demand for new aircraft by the airlines, in order to support the world travel demand requirements over the next twenty years. Considering that the market outlook calls for $2.8 trillion in terms of new revenues, and that a significant portion of this will ultimately accrue to the supplier base, neither Airbus nor Boeing can ignore the imperative to transform the capabilities of their supplier networks and their supply chain management practices as the most critical aspect of their competitive strategies. The smallest gains in supply chain management operational efficiency could drive substantial financial wins for either company, protecting margins, while simultaneously allowing the manufacturers to offer competitive pricing to airline customers in support of long-term positioning within the marketplace.

This paper will offer insights into world class supply chain management practices that have been predominantly utilized by Toyota that are scalable and could be leveraged in the commercial aerospace industry. The remaining central question is which aerospace behemoth will take action to aggressively transform its supply chain management practices in order to establish long-term market domination. If one of the two manufacturers can more successfully exploit these supply chain management opportunities, and thus capitalize on immense future-state gains, the predictable consequence for the other could well mean its long drawn-out demise.

2 INTRODUCTION

Admittedly I am a fan of the Toyota Motor Corporation. The company has been able to incrementally build-up its global presence to become the top producer of automobiles in the world. While Toyota's annual sales have been impressive, I am not particularly concerned about the company's market share in the automotive industry. Rather, I am interested in how the company has crafted its production system, known the world-over as the Toyota Production System (TPS). The TPS has become Toyota's strategic weapon in the automotive marketplace and while many corporations have adopted the tools associated with the TPS, very few have been able to master and fully apprehend the company's principles, practices, and methodologies; holistically transplanting the heart of the TPS into their DNA.

Nevertheless, Toyota has been able to carry-over its TPS principles, practices, and methodologies working with supply chain networks around the globe to grow, cultivate, and produce very impressive business results. As an employee that works in the aerospace industry, an industry that utilizes many of the tools and concepts Toyota utilizes; I am perplexed at why the aerospace industry, specifically Airbus and Boeing, have not attempted to fully adopt the TPS. In the highly competitive large airplane market sector, which consists of airplanes produced with more than 100 seats, it would seem the OEM that were to fully grasp and incorporate the principles, practices and methodologies associated with the TPS first, would formulate a distinct advantage in the commercial aerospace industry. In fact, if one of the aerospace OEMs were able to adopt the TPS and strategically leverage its practices working with its supply chain networks, the smallest gains would drive significant financial wins, not only for the OEM, but for its supply chain networks and ultimately airline customers.

2.1 Thesis Hypothesis

Toyota's use of the TPS is much more than the simple deployment of tools that incrementally take waste out of the company's production system. While the TPS tools are important, there are very important aspects of the TPS engrained in the company's guiding precepts, management principles, and methodologies that have not been adopted successfully by other companies. My contention is that the first commercial aerospace OEM that fully understands, adopts, and implements the TPS will create a distinct competitive advantage in the commercial aerospace marketplace. This competitive advantage would translate into a sharp difference between what it means to be the number one, and number two, airplane manufacturer in the world, shaping the creation of a significantly different focus on how the aerospace industry and Wall Street measure business performance within the aerospace industry. Traditionally the marketplace has tracked annual competitions to determine which OEM sells more airplanes to achieve greater market-share. This basically reflects the belief that high-volume production means lower costs through scale economies, leading to improved margin performance by the OEMs. Accordingly, future measures would focus on achieving greater operational efficiency by reducing transaction costs, minimizing process waste, improving flow, and eliminating quality defects in the system.

The following example should outline the context of the TPS and its relation to cost. Let's say there are two companies, Airplane Producer 1 (AP1) and Airplane Producer 2 (AP2). Both companies have an airplane product that supports the market-sector for airplanes in 150 seat range. Customer A (CA) is looking to buy 100 of the 150 seat airplanes and has notified AP1 and AP2 that it intends to split the sale, with 60% going to the winner and 40% going to the loser. Through an extremely competitive sales campaign, AP1 was able to win the sales competition, garnering 60% of the sale, while AP2 received 40% of the sale. However, because the competition was extremely tight and AP1 wanted to sell more airplanes than AP2, AP1 discounted its product 5% to win the large sales order from CA. Thus, AP1 sold its airplane for $95, while AP2 sold its airplane to CA for $100. When the sale is announced to the public, Newspaper A reports, "AP1 wins a significant order, while AP2 continues to trail in total market-share." The newspaper also details that at list prices, $110, AP1 netted a sale worth approximately $6600 and AP2 netted a sale worth approximately $4400." The newspaper also reports, "With large bulk sales OEMs typically offer discount pricing to their customers."

For the last five years, AP2 has been working to implement the TPS; in the last year the company began working with its supply chain networks to take wastes out of the system. Although early into the transformation process, AP2 was beginning to see significant continuous improvement gains using the principles, practices and methods associated with the TPS. The company projected it has taken roughly 3% of its total operating cost out of the entire system. The total system-based cost for AP2 to produce its 150 seat product costs the company $75. In addition, through the application of the TPS, AP2 was able to speed up flow in its production line by 10 days; it now takes the company 15 days to produce an airplane. Through continuous improvement opportunities AP2 has achieved, the company does not need to invest any capital to produce the volume of airplanes CA has purchased.

During the same time period, AP1 has stayed the course maintaining its traditional production system philosophy; it takes AP1 24 days to produce an airplane and its system-based cost to produce an airplane is $77.25. Because of some capacity constraints associated with AP1's manufacturing and assembly facilities, the company needs to invest $75 to procure additional rate tooling to build the airplanes CA purchased.

So who won the sales competition? Let's take a look! We know the following:

Gross Revenue

- AP1 actual sales gross revenue: 60 airplanes * $95 = $5,700
- AP2 actual sales gross revenue: 40 airplanes * $100 = $4,000

Total System-Based Cost

- AP1 total system based cost: [(60 airplanes * $77.25) + $75 Rate Tooling = $4,710
- AP2 total system based cost: 40 airplanes * $75 = $3,000

Net Profit

- AP1 net profit = $5700-$4,710 = $990
- AP2 net profit = $4000-$3000 = $1000

ROI

- AP1 ROI: [($5,700-$4,710)/$4,710]*100 = 21%
- AP2 ROI: [($4,000-$3,000)/$3,000]*100 = 33%

Fully-Burdened Inventory Holdings (Assuming 70% Sourcing)

- AP1: 24 days of flow * ($77.25*.3) = -$556.2
- AP2: 15 days of flow * ($75*.3) = -$337.5

Inventory Cost Avoidance through Flow Reduction Efforts

- AP1: 24 days of flow * ($77.25*.3) - $556.2 = 0
- AP2: 25 days of flow * ($75*.3) - $337.5 = $225

Therefore, even though AP1 sold more aircraft than AP2, AP2 yielded far better business results financially through the incorporation of its TPS practices. AP1 would need to sell significantly more aircraft than AP2 on an annual basis to maintain a balanced playing-field from a financial and cost-based perspective, or it too could adopt the principles, practices, and methodologies associated with the TPS. An important consideration pertaining to the importance of the cost-based opportunities AP2 achieved in this scenario is that the company could use the financial gains it achieved to invest in tooling, technology advancements, and prospective product development opportunities.

Although the example above is very simple, it captures the importance of studying and learning the Toyota Production System's scalability to commercial aerospace supply chain management principles, practices, and methodologies. If Airbus or Boeing were to adopt and fully leverage the opportunities the TPS presents, the face of the commercial aerospace industry would forever be changed.

2.2 Thesis Methodology

The research communicated in this thesis has been achieved through primarily three methods of learning. The methodologies utilized are documented below:

1. Literature reviews – There are an extensive amount of literary writings on the TPS, thus the first step in the learning process associated with this thesis was to review and synthesis the writings associated with Toyota's precepts, management principles, and supply chain management methodologies.
2. Benchmarking – Through numerous years of working in the aerospace industry and through personal learning's I have take-in, I have been fortunate enough to visit many manufacturers that have successfully incorporated the principles, practices, and methodologies associated with the TPS, including trips to Toyota's Georgetown, NUMMI, and Toyota City manufacturing sites.
3. System Design and Management (SDM) Fellowship Program – As an SDM Fellow, I have been treated to the rich learning community the Massachusetts Institute of Technology offers its students. Every step of the way through this program has been enriching; one of the greatest learning's being the absolute confirmation of the importance of system of systems design and its correlation to system dynamics performance.

2.3 Chapter Overview

Following this introductory chapter, Chapter 3 provides an examination of Toyota's supply chain architecture. The discussion in this chapter focuses extensively on the foundation of Toyota's supply chain architecture, the company's precepts, management principles, and ability to incorporate its methodologies into the lifeblood, DNA, of the system's participants. Included in the discussion is a review of the company's architectural design, product development practices, leverage of supplier associations to build relationships within the company's supplier networks, and procurement methods. Chapter 4 gives an overview of the evolution of supply chain management practices in the commercial aerospace industry supply chain, by highlighting the significant milestone events and developments the industry has experienced endured during the last sixty years. Included in the discussion is an outline of recent movements in aerospace supply chain management design and focus, an overview of The Boeing Company's revolutionary 787 program, and the scalability of Toyota's TPS within the commercial aerospace supply chain management sector. Following this discussion, in Chapter 5, the attention of the thesis shifts to an exploration of transformational steps that would need to be taken in the future. Taking a roadmap approach, the discussion in this chapter examines the steps either Airbus or Boeing could take, going forward, to convert their current-state supply chain management architecture to a future-state architecture embodying the principles, practices, and methods associated with the TPS. Finally, in Chapter 6, concluding comments are provided by the author, including insights pertaining to important research findings gained from this study and specific areas where further research would benefit the aerospace industry in the future.

3 EXAMINING TOYOTA'S SUPPLY CHAIN ARCHITECTURE

In order to develop a full understanding of Toyota's superior supply chain management practices within the automotive manufacturing industry, it is crucial to gain a holistic insight into the company's overarching management principles, supply chain management architecture, product development procedures, and ability to leverage collaborative relationships with its partners to establish competitive advantage in the marketplace. The combination of these four aligned system elements are what differentiates Toyota's performance from its competition and enables the company to leverage incremental growth annually that has catapulted it to rank first in terms of global sales, net worth, revenue and profit in the automotive industry.

3.1 Toyota's Guiding Precepts, Management Principles, and DNA

To understand the success Toyota has achieved during the course of the last sixty years, one must understand the guiding values and management principles the company successfully incorporated into its DNA, long before the terms Toyota Production System (TPS) or lean manufacturing became part of the everyday language within the business community. Many authors have already documented the essence of Toyota's guiding precepts and management principles. In the discussion below, for brevity, we will concentrate on just a few of them that are quite illustrative of the wider literature on the Toyota Production System (TPS). In particular, we will focus on three specific contributions: 1) *Inside the Mind of Toyota* (Hino 2006), 2) *The Toyota Way* (Liker 2004), and 3) *Decoding the DNA of the Toyota Production System* (Spear and Bowen 1999).

We will look at these writings in succession, first analyzing Hino's detailed account of Toyota's guiding precepts, all of which he attributes to being embedded in Toyota's very DNA. Then we will conduct a thorough examination of Liker's well publicized documentation of Toyota's 14 Management Principles. Lastly, we will conclude by reviewing the account of Toyota's DNA provided by Spear and Bowen. These writings will provide a sufficiently representative understanding of how Toyota operates as a company and how the company utilizes and demonstrates these overarching principles in its daily management practices. Without a complete understanding of these extremely important elements, neither aerospace behemoth could expect to successfully implement TPS principles within their respective production systems. The fact is that these precepts and principles are what glue the TPS together. Taken separately and in isolation, TPS would just be just a set of continuous improvement tools focused on incremental improvement.

Toyota's Guiding Precepts

With the release of the English version of Satoshi Hino's *Inside the Mind of Toyota*, translated in 2006, readers were granted very detailed and well documented insights into the early days of Toyota, including the founding precepts that, over the course of several decades, have endured very little change and continue to guide the company in present day business dealings. Based in part on Hino's account, we will examine the contributions that Sakichi Toyoda, Kiichiro Toyoda, Eiji Toyoda, Taiichi Ohno, and Shoichiro Toyoda made during their tenures at Toyota that helped shape and craft the guiding precepts of the company. The importance of these guiding precepts cannot be understated, as they have provided a beacon for Toyota's leadership and employees at all levels, guiding their work within the Toyota Production System. It is indeed difficult to imagine what the consequences might be if either Airbus or Boeing should fail to learn the lessons distilled from Toyota's evolution as both of these companies push ahead with their enterprise transformation efforts, including the transformation of their supplier networks, to enhance their competitiveness, imbue their employees with a sense of ownership, and enrich the society as a whole.

Sakichi Toyoda[1]

Sakichi Toyoda was inventor of the Toyoda-style looms and founder of the Toyoda Automatic Loom Works. Never once in his career did he work in the automotive industry. That said, while amassing a fortune inventing looms, Sakichi had the foresight to set aside capital and challenge his eldest son to develop automobiles and enter the automotive industry. "Build cars and serve your country, Sakichi is said to have told his son Kiichiro" (Hino 2006, p. 2) Although generating the capital to fund the development of automobiles was a very important endeavor in Toyota's history, perhaps the most important contribution Sakichi made to the company was the precepts that he laid out when inventing looms. While Sakichi never documented his guiding values, Kiichiro and his son-in-law Risaburo had the presence of mind to capture and document them (Hino 2006, p. 2). The initial Toyoda precepts were documented as follows (Hino 2006, p. 2):

1. Regardless of position, work together to fulfill your duties faithfully and contribute to the development and welfare of the country.

[1] In Japan, the family name appears first. So, for example, the members of the Toyoda family would usually be referred to as Toyoda Sakichi, his son Toyoda Kiichiro, Kiichiro's cousin Toyoda Eiji, and so forth. For ease of reference, we follow here the Western tradition of first name followed by the family name.

2. Always stay ahead of the time through research and creativity.
3. Avoid frivolity. Be sincere and strong.
4. Be kind and generous. Strive to create a home-like atmosphere.
5. Be reverent and conduct your life in thankfulness and gratitude.

Therefore, through his daily management principles and values, Sakichi Toyoda was able to provide generations of future employees working for the Toyota Motor Corporation a foundation to work from, providing specific guidance and scope to contribute to the company's evolutionary transition from the loom business to the automotive industry.

Kiichiro Toyoda

In the early twentieth century, Kiichiro Toyoda toured European and American industry visiting automobile manufacturers; it was during his visit to America that Kiichiro became focused on automobile production, specifically Henry Ford's mass production methods utilized to produce cars; "[t]his was the genesis of Kiichiro's dream of building automobiles" (Hino 2006, p. 4). Within 12 years, Kiichiro had succeeded in launching his dream, under the direction of his father Sakichi who had passed away in 1930; he established an automotive division within his father's loom business.

During his visit to America, Kiichiro had the prescience to identify that Japanese industry would not be able to adopt all the same processes that were enjoyed by companies in the West.

For Kiichiro, being able to compete on an equal footing with automotive manufacturers in the advanced countries of the West meant having to work out uniquely Japanese methods for high productivity and low cost. One of the elements of this approach was the "just-in-time" method (i.e., making what is needed, when it is needed, and in the quantity needed) (Hino 2006, p. 5).

In addition to "just-in-time" processing, a cornerstone of the TPS, Kiichiro also established additional values that have carried over into the modern Toyota precepts, they include focusing on quality and cost.

In fact, Kiichiro's philosophy pertaining to quality, focusing primarily on two elements: 1) "Study what customers want and reflect that in your product" (Hino 2006, p. 6) and 2) "Improve the product by auditing the production system, as well as the product itself" (Hino 2006, p. 6). These principles were far ahead of their times. The notion of examining upstream quality defects was in itself revolutionary. Examining defects as early as possible into the product's manufacturing cycle helped identify multiple root-cause reasons contributing to the defects. "These factors included immature design and production technologies, ignorance about how a product was used, and careless design errors" (Hino 2006, p. 7). Hence, Kiichiro identified a scientific approach to observing and finding the root-cause of defects in the system, thus enabling workers to eliminate waste from the system.

With respect to cost, Kiichiro focused on the price of the product that would entice customers. Rather than using the prevalent cost accounting techniques of the day, Price = Cost + Profit, Kiichiro borrowed from Henry Ford's philosophy and established the precedence of looking at cost from the viewpoint that Profit = Price – Cost (Hino 2006, p. 8). The concept of cost accounting Kiichiro introduced will be of paramount importance in transforming aerospace supply chain practices. We will present a closer examination to the cost accounting principles that have propelled Toyota later in this paper, specifically in section 3.5 – Toyota's Procurement Methods.

Kiichiro launched the Toyota Motor Company, later known as the Toyota Motor Corporation, and put into practice the basic Toyota precepts and his own innovative approaches to management. This is captured succinctly by Hino (Hino 2006, p. 10):

> Broadly speaking, one sees Kiichiro's legacy as the fundamental strategies to overcome the important management challenges of each stage of the company's development. Rather than relying on technology imported from the West, he instead took the long view that Toyota would never be able to compete with Ford and General Motors without securing an independent automotive manufacturing base.

Simply put, Kiichiro was not only the founder of Toyota Motor Corporation; he was the innovator who laid the initial foundation for Toyota's management principles.

Eiji Toyoda

Eiji Toyoda, who was president of Toyota Motor Company from 1967 to 1982, is widely recognized as the leader responsible for creating the Toyota people know today. Brought into Toyoda Automotive by Kiichiro Toyoda, Eiji never forgot the words bestowed on him by his uncle (Hino 2006, p. 17):

> Nobody has any business deciding whether we can make cars or not. The fact is that it's too late to back out. If you're a true engineer, then let us dream.

Eiji's contribution to the TPS was pervasive; he had no patience for waste. When he was brought into Toyoda, Eiji supported Toyoda's Auditing and Improvement Center, examining quality defects that had entered the production system. When he arrived, the level of defects in the system astonished Eiji. When speaking about that period of time working for Toyoda, Eiji is quoted as saying (Hino 2006, p.18):

> When we'd build a car that turned out to have a defect, we'd ask why the affected part was bad and look for the process that caused the problem. My role was to improve the process, since we figured that if we fixed the process, then there wouldn't be any more defects. Basically we were doing what would now be called QC.
>
> Many companies have accounting departments and general affairs departments, but both the name and the functions of our Auditing and Improvement Department we unique. It's the same now as it was then. We search out problems that need to be taken care of, and we focus knowledge and wisdom on them until they're solved.

It was through his examination of waste that Eiji identified the importance of aligning and integrating functional departments. He most likely did this through the identification that the internal organizations resisted working together when quality issues surfaced.

Perhaps Eiji's largest contribution to modern day Toyota was his due diligence in creating the learning organization. Through his steadfast incorporation of the precepts that had been passed to him from Sakichi and Kiichiro Toyoda, Eiji was able shape organizational learning based on experimentation. "What made Eiji unique was his limitless humility and diligence in the face of facts and truth" (Hino 2006, p.20). Eiji portrayed the Toyota precepts and as the leader of Toyota Motor Company provided all of his employees a beacon of leadership and guidance on how to best support and contribute to the company.

Taiichi Ohno

> Ohno transferred to Toyota Motor in 1943 and set about reforming its manufacturing division. After the war, Kiichiro instructed Ohno to "catch up to America" in three years. As Ohno came to grips with the task of revolutionizing production, he began crafting the unique Toyota Production System that some have referred to as the "Ohno Production System (Hino 2006, p. 20).

Ohno, possibly the most famous architect of the TPS, was a great inventor, but also continued, reinforced, and elevated the Toyoda precepts to a higher-level. Leveraging the teachings of Kiichiro Toyoda, Ohno initiated concepts such as the 5-Whys and Go See techniques, which were pointed at challenging Toyota team members to see beyond the surface to identify root-cause defects and wastes in the system. Ohno's greatest contributions to Toyota came in the form of reinforcing the importance of inventory awareness, adding a human element to automation and reaching out. Ohno's approach to inventory awareness was relentless.

> A person in business may feel uneasy about survival in this competitive society without keeping some inventories of raw materials, work-in-process, and products. This type of hoarding, however, is no longer practical. Industrial society must develop the courage, or rather the common sense, to procure only what is needed when it is needed and in the amount needed, (Ohno 1988, p.15).

Upon stabilizing manufacturing processes, Ohno always challenged employees to decrease inventory levels beyond what the operating plan called out for, since excess inventory created waste, generating unnecessary cost.

Reinforcing the importance of the learning organization and reducing inventory procured, Ohno initiated automation with a human element, referred to within Toyota as Autonomation. Autonomation, provided dual roles in the system's design, "it eliminates overproduction, an important waste in manufacturing, and prevents the production of defective products" (Ohno 1988, p. 8). With the elimination of overproduction, excess materials were eliminated from the production system that would normally be procured, thus, reducing inventory levels. The second element of Autonomation that Ohno had introduced within Toyota included the added human element to create visual inspections. Creating a management system by sight, Ohno was able to ensure the development of processes focused on "bringing production weaknesses (in each player that is) to the surface" (Ohno 1988, p. 8). Therefore, utilizing a management system by sight approach enabled quick opportunity identification for employees' development to contribute to the production system's performance. Hence, through the use of Autonomation, Ohno was able to perpetuate Kiichiro's and Eiji's values associated with stimulating the system through the cultivation of a learning organization and experimenting to continuously improve the system.

Ohno's teachings pertaining to reaching out were straightforward. He believed that between processes a zone of cooperation between employees existed. Ohno oftentimes characterized this type of exchange utilizing a track and field relay race analogy to describe the process of reaching out. The intent was that "production processes will always be unevenly balanced, but the product can flow smoothly overall when processes can absorb one another's variability" (Hino 2006, p. 23). Utilizing this technique ensures that as one of Toyota's products passes from one team member to the next, the process is maintained and controlled.

Shoichiro Toyoda

Shoichiro Toyoda worked hand-in-hand with Eiji Toyoda to shape Toyota, eventually becoming the president of The Toyota Motor Corporation. In fact, two of his efforts are very important within the history of Toyota: 1) completing the vision of Eiji, he integrated Toyota Motor and Toyota Motor Sales together to form The Toyota Motor Corporation, 2) providing the world with Toyota's updated precepts in 1990 that were slightly modified in 1997. The updated precepts are defined as follows (source: www.toyota.com):

1. Honor the language and spirit of the law of every nation and undertake open and fair corporate activities to be a good corporate citizen of the world.
2. Respect the culture and the customers of every nation and contribute to economic and social development through corporate activities in the community.
3. Dedicate ourselves to providing clean and safe products and to enhancing the quality of life everywhere through all our activities.
4. Create and develop advanced technologies and provide outstanding products and services that fulfill the needs of customers worldwide.
5. Foster a corporate culture that enhances individual creativity and teamwork value, while honoring mutual trust and respect between labor and management.
6. Pursue growth in harmony with the global community through innovative management
7. Work with business partners in research and creation to achieve stable, long-term growth and mutual benefits, while keeping ourselves open to new partnerships.

The significance of Shoichiro's contributions are that he helped carry on the foundational principles that had been established by his predecessors while concurrently establishing Toyota Motor Corporation as a global company. As a global company Toyota has carried forward these very precepts into every country it has entered both as a seller and producer, including many of the countries where Airbus and Boeing conduct business on a regular basis. These precepts embody what Toyota openly communicates as the TPS, which it collaboratively shares with its partners, and most importantly, which makes a direct contribution to society as a whole.

Toyota's 14 Management Principles

Jeffrey Liker's book *The Toyota Way* provides deep-rooted knowledge of The Toyota Motor Corporation's management principles. Most fundamentally, Liker examines Toyota's guiding principles and utilizes his well-researched findings of Toyota's guiding principles and elements of the Toyota Production System (TPS) to craft "The 14 Management Principles." These principles deserve close scrutiny in light of the focus of this thesis on the adaptation of Toyota's supply chain management practices in the commercial aerospace sector. Two important questions, consequently, need to be addressed, as to whether other commercial aerospace companies have successfully adopted elements of TPS within their systems and also whether the TPS management principles be scaled up and adopted more widely by the commercial aerospace sector as an integral part of the industry's new DNA.

In his book, Liker groups The 14 Management Principles into four broad categories, represented in the pyramid diagram (see Figure 3-1). The four elements begin at the bottom and progress upwards, supporting the TPS House.

These four elements are: 1) Philosophy – Long Term Thinking, 2) Process – Eliminate Waste, 3) People and Partners – Respect, Challenge and Grow Them, and 4) at the pinnacle, Problem Solving – Continuous Improvement and Learning (Liker 2004, p. 70).

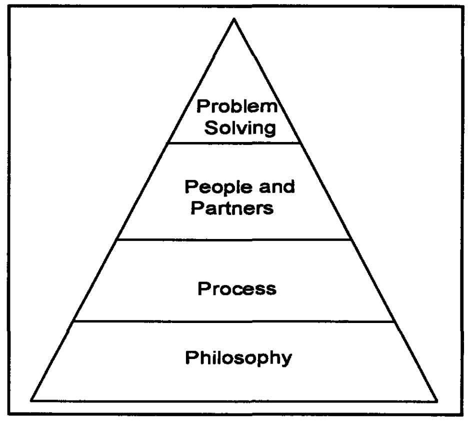

Figure 3-1: Four Categories of 14 Management Principles
Source: Liker (2004, p. 13)

In addition, Liker references the "TPS House" (Liker 2004, p. 33) identifying The Toyota Way Philosophy as the foundation of the system's structure, a captivating reference because most depictions of the TPS House that have been produced in Western writings, highlight the tools and outputs associated with the TPS and not the embedded cultural elements or principles. Liker specifically calls-out that the TPS House diagram is intended to reflect a "system based on structure, not just a set of techniques" (Liker 2004, p. 33). The specific elements contained within the foundation of the TPS House include (from the bottom up): Toyota Way philosophy, Visual Management, Stable and Standardized Processes, and Leveled Production (*heijunka)*. Two main walls on both sides refer to Just-in-Time (on the left) and *Jidoka* (in-station quality) on the right. At the center, moving upwards, are Waste Reduction, leading to Continuous Improvement, enabled by People and Teamwork. The entire structure supports the roof – Best Quality, Lowest Cost, Shortest Lead Time, Safety, and High Morale (Liker 2004, p. 33).

In the second section of his book, Liker proceeds to provide a detailed discussion encapsulating each of the fourteen principles. We will take an in-depth look to examine these fourteen principles, keeping in mind their scalability and relevance to supply chain management practices and principles that would need to be incorporated into the DNA of either one or both of the two aerospace behemoth's.

Principle 1: Base Your Management Decisions on a Long-Term Philosophy, Even at the Expense of Short-Term Financial Goals

The viewpoint that proves foundational in Liker's writings is the belief that a strategic long-term view must be taken to drive, enhance, and cultivate business growth. This long-term commitment is focused on what is best for the customer and reinforces the belief that Toyota's focus starts and ultimately ends with its customer base. Liker reinforces the point that although difficult, Toyota puts its long-term commitment to its business objectives ahead of short-term financial gains, a strategic element both Airbus and Boeing have clearly neglected, much to their detriment. This has been amply demonstrated by the well-chronicled downward slides in production levels associated with each of the companies' most recent derivative program launches, the A380 and 787. As demonstrated by these production slides, both Airbus and Boeing have underestimated the absolute need to cultivate, align and integrate their global supply chain partners into their globalization process by going beyond the traditional "build-to-print" model so prevalent in the industry in the past. As a result, they both have paid dearly in the form of not only the severe penalty that comes with sliding production levels but also the significantly higher costs than could have been earlier foreseen or tolerated. Meanwhile, the high risk proposition of delegating substantially greater responsibilities to suppliers without first heeding the basic lessons offered by Toyota has often reverted to the traditional "build-to-print" practice, in the hopeful expectation that this may serve as a transitional step in the evolution of the industry's supply chain management practices.

Unfortunately for Airbus and Boeing, neither OEM was ahead of the curve to prevent the disruption looking them in the eyes. Rather, both companies reacted to their broken productions systems, which had lacked embedded countermeasures to prevent the spread of system disconnects. In large part, when the companies began to unearth their overall system problems within the respective value streams of both derivative programs, the problems had already escalated at a catastrophic rate, thereby causing significant production delays, public embarrassment, impacting market performance, government relations, and ultimately slashing into the morale of each of the companies' employees. Within the Toyota Production System, these disconnects simply would not have happened; Toyota would have worked with its partners and headed off the disruption before it even would have become a minor ripple leaving the trace of hardly any impact in the system.

For example, in the process of its globalization strategy, one of the methods Toyota has utilized to mitigate system risk has been taking the "Toyota DNA" -- a term attributed to a popular writing by Spear and Bowen that we will examine later in the thesis -- and infusing it into different global cultural contexts where the company performs work. In order to overcome similar risks facing it at a global scale, Toyota has taken and demonstrated strict discipline, taking a long-term perspective and approach to meeting the challenge of cultivating its global position within the automotive industry. In doing so, Toyota has leveraged the following operating principles in its global expansion efforts to demonstrate the company's responsibility to its business partners to instill stable, long-term growth, and mutual benefits (Liker 2004, p. 81):

1. Honor the language and spirit of the law of every nation and undertake open and fair corporate activities to be a good corporate citizen of the world.
2. Respect the culture and the customers of every nation and contribute to economic and social development through corporate activities in the community.
3. Dedicate ourselves to providing clean and safe products and to enhancing the quality of life everywhere through all our activities.
4. Create and develop advanced technologies and provide outstanding products and services that fulfill the needs of customers worldwide.
5. Foster a corporate culture that enhances individual creativity and teamwork value, while honoring mutual trust and respect between labor and management.
6. Pursue growth in harmony with the global community through innovative management
7. Work with business partners in research and creation to achieve stable, long-term growth and mutual benefits, while keeping ourselves open to new partnerships.

Utilizing these principles in all aspects of its global expansion, Toyota had to build trust, mutual trust with employees and in the cultures where its facilities would ultimately be located. In addition, Toyota strategically has cultivated its supply chain relationships in the countries it conducts business. For instance, in its North American business dealings, Toyota has grown internal production of parts being built within the United States, Canada, and Mexico, so that nearly 70% of the materials and components integrated into its products' designs are home grown; when Toyota first began producing cars in North America, it was still importing roughly 70% of its parts from Japan to support production.[2]

What Toyota has demonstrated is that through its systemic approach to running and cultivating business, the company will work, grow, and align its business objectives towards a higher purpose that is much more important than netting immediate financial returns.

Principle 2: Create Continuous Process Flow to Bring Problems to the Surface

Liker leads into this second principle with the assertion that "most business processes are 90% waste and 10% value-added work" (Liker 2004, p. 87) throughout the value stream. Elimination of muda (waste) is the primary target of any lean initiative. If one focuses on reducing 90% of the problem, then the implementation will see the quickest return. This is done through the process of continuous improvement, *kaizen.* Liker cites the eight types of muda as (Liker 2004, p. 89):

1. Overproduction
2. Waiting
3. Unnecessary Transport
4. Overprocessing
5. Excess Inventory
6. Unnecessary Movement
7. Defects

[2] Toyota Benchmarking Session, Georgetown, KY. August 2006

8. Unused Employee Creativity

As opposed to traditional mass production methodologies, which are still utilized throughout the aerospace industry today, Toyota's use of these principles is based on the concept that the quickest way to reduce waste and eliminate defects is through the utilization of one-piece continuous flow processing. Liker highlights that one-piece flow yields the following seven benefits (Liker 2004, pp. 95-96):

1. Builds in Quality
2. Creates Real Flexibility
3. Creates Higher Productivity
4. Frees Up Floor Space
5. Improves Safety
6. Improves Morale
7. Reduces Cost of Inventory

An important aspect Liker draws upon that cannot be lost is when he outlines the importance of one-piece flow, unlike in traditional mass production processes where batch processing is predominantly utilized, the batch processes cover up issues in the process flow. One-piece flow immediately highlights where waste exists in the process being performed. Just as many of Toyota's competitors in the automobile industry perform with traditional batch and queue processing, the aerospace industry is overly steeped in the practice. Within aerospace, the process impacts generated with batch and queue techniques are very severe, often times leading to spiked, false demand for of raw materials within the supply -chain that causes shortfalls for suppliers and speculative or anticipatory increases in raw material prices. In aerospace, having a predictable and steady flow rate involving raw materials and supplied components would be integral to achieving one-piece flow. How could this be done? Using the order rate and the available labor hours, one can determine the rate at which each piece should be processed at a workstation. This time is the *takt time*; *takt time* paces the rhythm of the manufacturing floor. Throughout his discussion of this principle, Liker cautions that moving to one-piece is not easy. Initially it will be rough and even discouraging since problems that were covered up by the old processes will immediately surface. The culture of problem solving and perseverance needs to be in place to achieve the desired result.

Principle 3: Use the "Pull" Systems to Avoid Overproduction

This principle is one of the two walls of the TPS House (see Figure 3-2). The pull system, producing only the required material after the subsequent operation signals a need for it is critical for preventing overproduction.

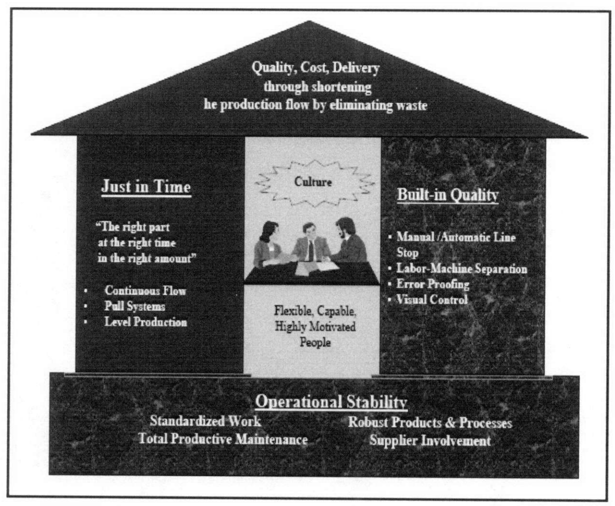

Figure 3-2: TPS House

Source: Lamb and Liker (2000, p.17)

As in many Japanese manufacturing systems, the key to controlling this is the kanban. *Kanban* is a mechanism used to signal for a specific amount of material. Liker stresses that these systems should be simple systems, not complex computerized systems.

While Liker is absolutely correct that these systems should be simple, it is important to note that Toyota has implemented e-kanban techniques. Having seen the e-kanban practice in work when visiting Toyota's Georgetown, KY, facility, it was very evident that Toyota had stuck with the simplistic structure kanban systems require.

I was also lucky enough recently to talk with a Shingijutsu consultant about e-kanban, when I asked him about e-kanban; he advised me that it is an absolute necessity for Toyota to implement e-kanban practices. He advised, specifically: "Toyota's growth has been significant in recent years; with the growth, Toyota's quality system has been stretched, so e-kanban aligns and synchronizes all the elements of the traditional kanban system; however, it allows for easier tracing of parts in the system, which in turn has built a countermeasure to ensure quality and traceability of parts in the system."[3] An interesting point to reflect upon was that, after discussing e-kanban with him for a couple of minutes, the Sensei with whom I was speaking pondered for what seemed like a long while and said, "it will be very important for Toyota to stick with the simple practices of kanban, if they do overcomplicate practices like I have seen in aerospace with ERP, then e-kanban will take a toll on Toyota's quality."[4]

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[3] Discussion with Sensei Niwa, September 2007.
[4] Discussion with Sensei Niwa, September 2007.

Liker also points out that pull systems may not be appropriate to use in all instances. Pull and push may be needed. Factors affecting this are criticality of parts, manufacturing and delivery time and precedence of leveling flow. Within aerospace, this balance would certainly need to be identified; however, in traditional fabrication and manufacturing processes, I believe that a significant portion could adopt and transition to single-piece pull systems.[5]

Principle 4: Level Out the Workload *(Heijunka)*

When discussing this principle, Liker describes the need to level production; removing peaks and valleys caused by batch and queue processing and fluctuations in customer orders. Before going into detail to discuss leveled production, Liker discusses the three M's. While Liker provides a very good summary of the three M's in *The Toyota Way*, I believe the following summary from Taiichi Ohno is much more elegant (Ohno 1988, p. 41):

> If the meaning of "defective" goes beyond defective parts to include defective work, then the meaning of "100 percent defect-free products" becomes clearer. In other words, insufficient standardization and rationalization[6] creates waste (muda), inconsistency (mura), and unreasonableness (muri) in work procedures and work hours that eventually lead to the production of defective products.
>
> Unless such defective work is reduced, it is difficult to assure an adequate supply for the later process to withdraw or to achieve the objective or producing as cheaply as possible. Efforts to thoroughly stabilize and rationalize the processes are the key to successful automation. Only with this foundation can production leveling be effective.

[5] Author's input based on 10 years of aerospace experience working with senior production experts with well over 30 years of aerospace experience.

[6] As noted in Ohno's Book, the term "rationalization" is frequently used in Japanese writings to indicate activities undertaken to upgrade technology, improve quality, and reduce cost. It may also mean reorganizing and integrating an industry while engaged in the above mentioned activities.

From Ohno's description of the importance of the three M's, we can now examine Liker's introduction of the term Heijunka, a Japanese term that means to level work flow. Heijunka is very important in optimizing the manufacturing line; the intended outcome of implementing Heijunka is that it helps to achieve the goal of minimizing waste, not overburdening people or equipment (muri) or creating uneven (mura) production levels. To achieve this, requires the understanding of customer demand and product mix. This can be very difficult to achieve and at times the goal of minimizing inventory must be sacrificed to maintain leveled production flow.

In the aerospace industry, because production volumes are considerably smaller than those in the automotive industry, one might assume this level of predictability would be quite easy to achieve. However, the communication forums and methods that the OEMs utilize actually limits providing succinct visibility into the operations of their supply chain partners, thus impeding product flow predictability. Unfortunately, many broken processes exist in the aerospace industry, one specifically being the late release of engineering to accommodate mass customization and variability in design between units produced. While these factors should still be predictable, in many instances flow becomes compressed and a trickle-down effect occurs, where the impacts cascade and disrupt the system's flow. Once this happens, recovery becomes necessary. This, in turn, causes a cascading of waste and transaction-based cost throughout the system's performance, ultimately driving costs up in the production system.

Principle 5: Build a Culture of Stopping to Fix Problems, to Get Quality Right the First Time

This principle is the second of the two walls of the TPS house introduced in Liker's introduction of *The Toyota Way*; the emphasis of this principle is to build-in quality or Jidoka into processes. Liker illustrates this principle through the example that any person in a process has the authority to stop processing and signal a quality issue. Any person within Toyota can do this through the use of an Andon cord, a mechanism that signals a visual control reflecting that the line has stopped in a particular portion of the system, in both white and blue collar process areas. Liker reminds us that the entire production line is not brought to an immediate halt, but rather there is the potential for this to happen if the problem is not solved within the limited length of time for a solution is to be implemented in light of the fact that there is work-in-process that would be disrupted by a shut-down of the production line. When the line stops the "5-Whys" philosophy of problem solving is introduced, reinforcing the notion that Toyota's 14 Management Principles do not stand alone and that they are, in fact, intricately dependent upon each other, often exhibiting multiple dependencies at any given time. In this case, "5-Whys" are embedded in Liker's fourteenth principle, where the key point is being able to delve into and find the root-cause source of the problem. Within aerospace, as already highlighted by the references to the A380 and 787 programs, root-cause problems are often missed because flow does not drive the system. Liker contends and outlines that root-cause problem identification at the source is much easier in a continuous flow line since the time elapsed when a problem occurs in the system are reduced.

Principle 6: Standardized Tasks Are the Foundation for Continuous Improvement and Employee Empowerment

When examining Principle 6, Liker provides examples of how the TPS is based on an enabling bureaucracy, rather than a coercive bureaucracy. Liker highlights P.S. Adler's Social Structure (Figure 3-3) Model to demonstrate the behaviors associated with enabling and coercive bureaucratic structures. An enabling bureaucratic structure is one that is established on the empowerment of employees, utilizes rules and procedures as enabling tools, and leverages a hierarchical structure to support continuous learning. Leveraging the implementation of an enabling bureaucratic structure provides an infrastructure of empowerment that stimulates continuous improvement from the company's people and partners working within the boundaries of the system (Liker 2004, p. 145).

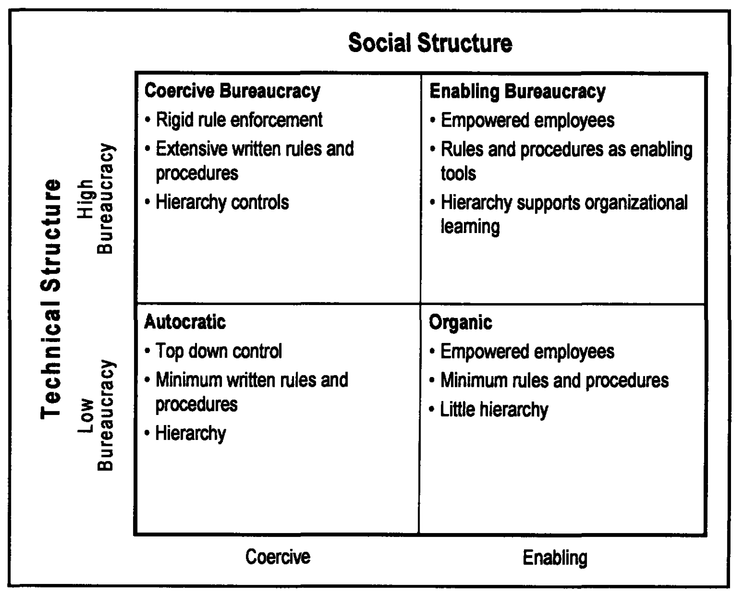


Figure 3-3: Coercive Versus Enabling

Source: Jeffrey Liker adopted from P.S. Adler, (2004, pp. 36-47)

Liker contrasts this to other bureaucratic structures that are rigid and inflexible that do not allow for growth and improvement. Specifically, he probes into effects caused from a coercive bureaucratic structure. Liker describes the coercive bureaucratic structure as one that embodies (Liker 2004, p. 144):

- Red Tape

- Tall, hierarchical organization structures
- Top-down control
- Books and books of written rules and procedures
- Slow and cumbersome implementation and application
- Poor communication
- Resistance to change
- Static and inefficient rules and procedures

To reinforce his point, Liker contrasts the coercive bureaucratic structure with the "destructive implementation" of Frederick Taylor's scientific work principles adopted by many companies following their introduction early in the twentieth century.

One industry, in particular, that adopted Taylor's practices was the aerospace industry; to this day, many of those practices continue to be engrained throughout the aerospace industry system. For instance, in the commercial aerospace today there are hundreds to thousands of detailed specifications, procedures, and policies that guide how suppliers interact with the primary manufacturing integrator.

As an employee working in the commercial aerospace industry, I have often times wondered why we have these very prescriptive steps in place, all of which we have mandated throughout the system, when only a handful of Federal Aviation Requirements (FARs) provide oversight to our production certificate. While I completely understand that the design, development, and production of our complex, engineering-intensive and technologically advanced products must be done with the highest integrity, the waste generated from this type of excessively detailed and documented set of specifications, procedures, and policies seems to be unnecessary. In fact, in many instances I have seen that the entrenched coercive bureaucratic practices have slowed us from providing or even reacting with value-added solutions that would enhance the system, ultimately providing better products and services to commercial airline customers and the flying public. On the flipside, Liker highlights that the enabling bureaucracy that the TPS encourages is the standardization of tested and proven methods that are geared at reducing waste. Hence, employees and partners working in the TPS, work with a sense of empowerment and purpose to contribute positively to the system's overall performance. Perhaps the argument in favor of less coercive procedures or less burdensome rules and regulations governing aerospace industry operations advanced here can be countered by asserting that aerospace products and systems must be absolutely fault intolerant and, hence, the presence of such invasive procedures are not only necessary for traceability of any defects but also a relatively small price to pay for safety.

Principle 7: Use Visual Control So No Problems Are Hidden

Principle 7 of *The Toyota Way* outlines the importance of visual controls used in a flow-based production system, "[d]eviations from the standard would create deviations from working to takt time, one piece at a time" (Liker 2004, p. 153). Liker highlights and promotes that visual controls are everywhere throughout the TPS. He goes on further to contrast Toyota with other Japanese automakers, specifically highlighting how most of Toyota's Japanese peers were operating and conducting business in the 1980s.

> The accepted dysfunction of the day was to see no problems and hear no problems until the hidden problems jumped up and bit you in the face. By that time, it usually wasn't a problem, but a fire-fighting crisis, and managers would spend much of their time jumping from putting out one fire to the next. In short, crisis management was the accepted mentality of the day (Liker 2004, p. 148).

The description that Liker provides sounds extremely familiar. If one were walking through either a Boeing or Airbus production facility today, they would see high-level visual controls – most of which have been adopted from examining and implementing elements of the TPS. For instance, the general public can take a tour of The Boeing Company's Everett, WA, facility and see the 777 Program moving line. When observing the line, all the high-level visual control facets of the TPS seem to be in place; however, upon closer examination the detailed visual controls that Toyota utilizes at the production cell level within its moving lines are absent. Therefore, when a problem arises, the immediate trigger to stop the line and correct the problem does not exist. In fairness to Boeing's 777 moving line concept, it does have production support cells in its final assembly area that are staffed with functional support (e.g., Material Handlers, Manufacturing Engineers, Industrial Engineering, and Quality personnel). Therefore, the right support personnel are in place to help mitigate production stops. However, at the installation level the visual controls do not exist for them to immediately respond to support the operators performing work. That is, these support personnel will only be notified if an operator or inspector engaged in assembly work will notify them and request their help.

One element of the TPS that has carried over throughout commercial aerospace manufacturing is 5S (see Figure 3-4). The 5S programs that have been adopted in the commercial aerospace industry, including the OEMs' supply chain partners, may not be at the level achieved by Toyota in its own operations, but the elements of 5S's: seiri, seiton, seiso, seiketsu, and shitsuke, have been widely adopted in aerospace and are practiced on a regular basis. Translated into English the five elements of 5S include (Liker 2004, p.150):

1. Sort – Sort through items and keep only what is needed while disposing of what is not.
2. Straighten (orderliness) – A place for everything and everything in its place.
3. Shine (cleanliness) – The cleaning process often acts as a form of inspection that exposes abnormal and pre-failure conditions that could hurt quality or cause machine failure.
4. Standardize (create rules) – Develop systems and procedures to maintain and monitor the first three 5S's.
5. Sustain (self-discipline) – Maintaining a stabilized workplace is an ongoing process of continuous improvement.

Together these steps are used to make all work spaces efficient, productive, reduce time looking for needed tools and improve the work environment.

While the aerospace behemoths and their supply chain partners have begun the process of leveraging visual controls and practicing 5S, their capability to ensure the proper level of detail and self-discipline still has quite a ways to go to enjoy the level of success Toyota has enjoyed. With years of practice and repetition, the learned knowledge of these practices should certainly carry-over and help benefit the aerospace industry, just as it has benefited those working in the TPS.

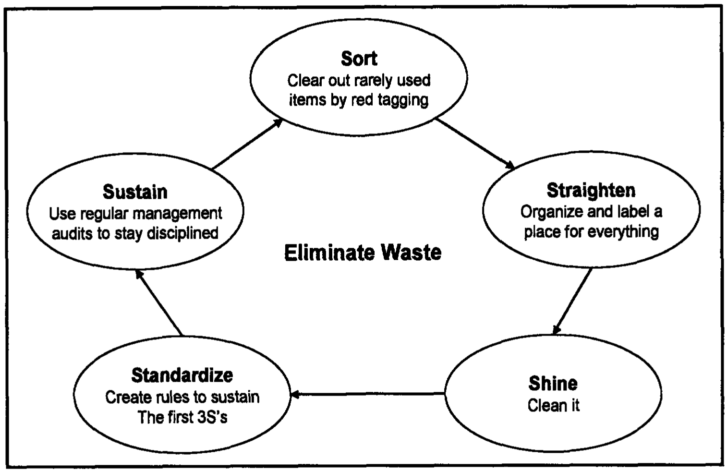


Figure 3-4: The 5S's

Source: Liker (2004, p. 151)

Principle 8: Use Only Reliable, Thoroughly Tested Technology That Serves Your People and Processes

When explaining Principle 8, Liker draws upon two critical supporting elements Toyota drives into its business decisions: 1) Adoption of new technology must support your people, process, and values; 2) People do the work, computers move the information (Liker 2004, pp. 160-161). Within aerospace these two supporting principles certainly have applicability. Examining Boeing's 787, a revolutionary composite airplane designed to leverage enhanced lifecycle economics primarily with better fuel efficiency and lower maintenance costs, it can be asserted that in virtually every aspect of the company – encompassing its basic values, people, processes, and supplier partners -- these basic Toyota principles do not seem to have been understood or adopted in developing and producing the airplane.

Rather than taking a steady approach to implementing the technological advancements introduced in the 787's design, Boeing and its partners proceeded forward and aggressively tried to push the technology into development. While they came close to making the schedule that was set forth, they ended up compromising their customer delivery commitments by six months and will ultimately be correcting system generated short-falls for years to come.

The same fate the 787 program recently endured was preceded by the Airbus A380. The well chronicled two-year delay of the A380 was significantly impacted with poor integration management from Airbus' technical community. In the case of the A380, engineers utilized different software platforms, CATIA V4 and CATIA V5, in the airplane's detailed design. The lack of integration and well thought-out use of common technological platforms generated significant amounts of waste. As a result, Airbus conducted considerable quantities of reengineering and production statement of work associated with wiring the mammoth airplane, hundreds of miles of wiring had to be reworked. This particular technological breakdown cost Airbus dearly, causing significant financial overruns, numerous leadership changes, and a serious stress for Airbus' supply chain partners. While the A380 program was delayed, Airbus' partners waited for payment, held inventory, and were constrained by a tremendous financial burden.

In contrast to the Boeing and Airbus examples, Toyota will venture into new technical fields, such as the use of hybrid engine technology. However, the TPS process will only bring in technology that will directly add value or reduce waste in a process. Implementation of new technological changes are pulled by manufacturing, not pushed by Toyota's Information Technology or Research and Development departments. Toyota maintains this course, because it is critical that processes are first streamlined and made more efficient prior to automation. The primary reason is that automated systems are more difficult to change and fine-tune than manual systems. Toyota does this masterfully, always ensuring minimal cost investment.

Principle 9: Grow Leaders Who Thoroughly Understand the Work, Live the Philosophy, and Teach It to Others

Liker leads into discussing Principle 9 with a very telling quote from Alex Warren, former Senior VP Toyota Motor Manufacturing, Georgetown, KY. Warren's quote outlines (Liker 2004, p. 171):

> Until senior management gets their egos out of the way and goes to the whole team and leads them all together... senior management will continue to miss out on the brain power and extraordinary capabilities of all their employees. At Toyota, we simply place the highest value on our team members and do the best we can to listen to them and incorporate their ideas into our planning process.

As Liker has done with many of the 14 Management Principles, he introduces supporting elements that complement Principle 9. The important elements that he highlights include (Liker 2004, pp. 173-181): 1) Grow your leaders rather purchasing them; 2) The role of the Chief Engineer; 3) Common themes of leadership at Toyota. We will examine these elements, again examining their relationship with those conducted in the commercial aerospace industry.

The point behind Toyota growing its leaders rather than buying them is that their leaders must embody and understand the principles of Toyota's culture. To do this, Toyota's leadership development candidates go through extensive mentoring, education development, and gain hands on knowledge of the system. For example, Fujio Cho, former CEO of Toyota Motor Corporation, "grew up in Toyota and was a student of Taiichi Ohno. He and Ohno provided a theoretical basis for the Toyota Production System (TPS) and the Toyota Way principles in order to teach them throughout the company "(Liker 2004, p. 172). It is through this very type focused approach that Toyota leaders reinforce the importance at all employee levels to cultivate a learning organization. Without the inherent, learned knowledge, an outsider would have a tremendous challenge coming in and understanding the system, while also trying to teach new principles. In other words, Toyota reinforces that fact that its leaders and people must live and breathe the principles, mentor peers, and implant the precepts of the company into its DNA.

Recently, Airbus and Boeing have made considerable leadership changes at the top of their respective companies. With these changes, both companies brought in outside leaders that changed the focus of each company. Let's take a look at some of the changes W. James McNerney, Chairman, President and Chief Executive Officer – The Boeing Company, has introduced since taking his leadership position July 1, 2005.

McNerney came into The Boeing Company during a period of turmoil that included scandals with the involvement of former Chief Financial Officer, Michael M. Sears and former Chairman, President and Chief Executive Officer, Harry C. Stonecipher. While the scandals Sears and Stonecipher were involved in were quite different, the bottom line was that each scandal impacted The Boeing Company's public image. As a result, one of the first initiatives McNerney promoted upon his arrival was that all employees conduct annual ethics recommitments. Next, McNerney introduced a new leadership model (see Figure 3-5) for all Boeing leaders to utilize and embody within daily management practice. While the new leadership model introduced a more rigid and focused platform for Boeing leaders to work in, it also stripped down management practices that had long brought very good business results to the company.

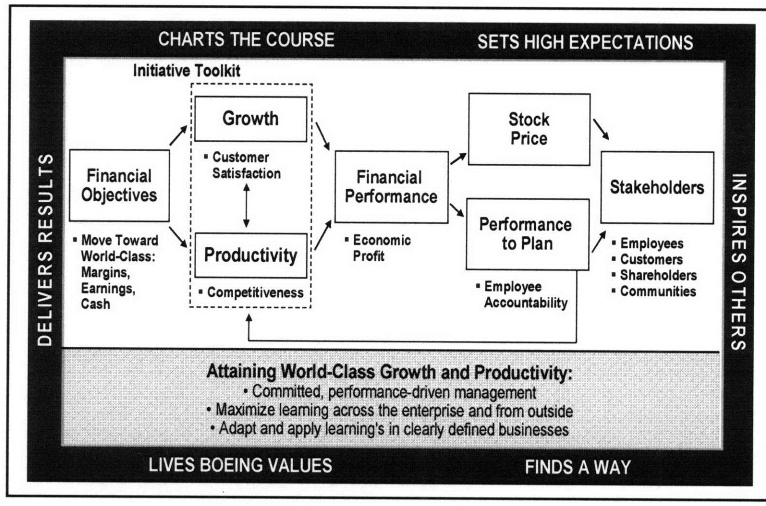


Figure 3-5: Boeing Leadership Model
Source: www.boeing.com

Furthermore, McNerney worked with the Boeing Executive Council to launch four major enterprise initiatives: 1) Lean+, 2) Global Sourcing, 3) Development Process Excellence, and 4) Initiatives Database. In launching these initiatives, very little substantive definition was provided in terms of what they actually meant or what the roles of leaders and employees should be in implementing them. In some instances, this also led to an identity loss for some employees – specifically those employees who had spent well over a decade working to align with Boeing's Vision 2016 (see Figure 3-6).

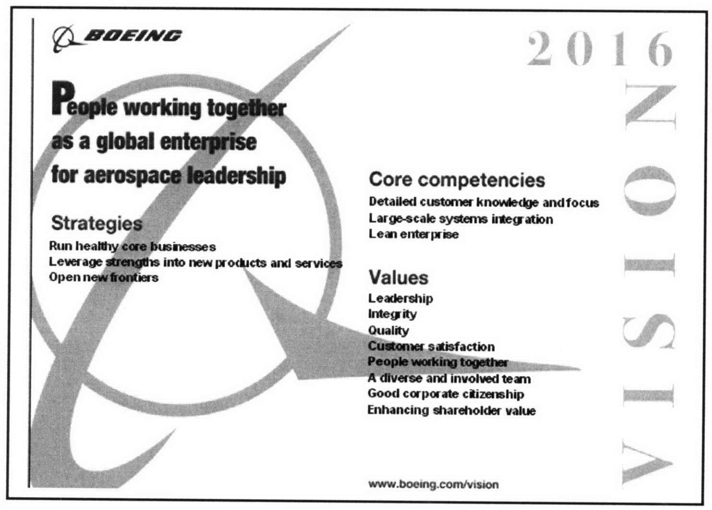


Figure 3-6: Boeing Vision 2016
Source: www.boeing.com

For example, Boeing's Integrated Defense Systems and Commercial Airplane business units had been very engaged in the deployment of Toyota based lean tool implementation efforts. With the launch of Lean+, no clarification of what the initiative entailed was given for employees to follow.

Since its inception, the Lean+ Initiative has left room for employees to wonder if they are implementing the right tools and has also brought about the introduction of numerous new tools. Moreover, the Lean+ initiative does not outline core precepts or principles. While efforts associated with the initiative have been well intended, they have lacked detailed tactical focus, ownership in development from employees, and have not been tested. The results have been quite the opposite of the principles Toyota has embraced over many decades, largely negating such ideas as cultivating employee empowerment and reinforcing the importance of the learning organization.

Nevertheless, although sketchy, McNerney's initial leadership initiatives are critical for Boeing. As an employee of Boeing, the steps he has taken were an absolute must, as they have driven a new level of tactical focus and structure leaders and employees can use to guide their work. I would also add that, while some employees had significant ownership in previous business models and practices, most of the existing best practices were leveraged in an ad-hoc fashion, rather than towards the benefit of the system as a whole. I genuinely believe Mr. McNerney's focus is towards system. While The Boeing Company may end up taking a couple of steps back initially, with a high-level of leadership accountability Boeing now has an excellent chance to achieve years of success in the future if the company sticks with the plan that has been outlined.

The role of Chief Engineer in Toyota is very different from the traditional role leveraged in aerospace. In recent years aerospace has begun to adopt many of the practices that have enabled Toyota to achieve considerable success. However, the adoption of these practices have been mostly through coincidence, not because Airbus or Boeing have modeled their Chief Engineer practices after the TPS. In Toyota, the Chief Engineer has responsibility, but not necessarily authority. Utilizing this philosophy requires that the Chief Engineer, working with the development teams, gains acceptance of his ideas through respect, knowledge and by proving that he is in fact offering the correct decisions to the teams. Therefore, the ability of the Chief Engineer to leverage and gain consensus for his leadership and his ideas is of critical importance. In the aerospace industry, by contrast, the Chief Engineer has for the most part enjoyed a top-down authoritative position.

With the understanding of Toyota's internal growth and development of leaders and how the role of Chief Engineer works, it is important to examine some of the themes associated with leading at Toyota.

> We have seen repeatedly that Toyota leaders are passionate about involving people who are doing the value-added work in improving the process. Yet engaging employee involvement by itself is not is not enough to define a Toyota leader... being a leader in Toyota also requires an in-depth understanding of the work in addition to general management expertise (Liker 2004, p. 181).

In Toyota, top-down management would be highly ineffective, it is simply too bureaucratic. According to Liker, Toyota develops its leaders such that they can (Liker 2004, p.182):

- Focus on long-term purpose for Toyota as a value-added contributor to society;

- Never deviate from the precepts of the Toyota Way DNA, and live and model themselves around this for all to see;
- Work their way up doing the detailed work and continue to go to the gemba (Go – See), the actual place where the real added-value work is done; and,
- See problems as opportunities to train and coach their people.

While the aerospace industry has begun the process of leadership transformation, to achieve the level of engagement Toyota leaders demonstrate, it will take quite some time for this to happen more fully. Leaders will need to transition from the role of expert generalists to extensively knowledgeable system leaders. Integral in this are a few critical features:

- Having responsibility without authority.
- Putting customer first.
- "Go and See" connect with the gemba where the real value-added work is performed.

Principle 10: Develop Exceptional People and Teams Who Follow Your Company's Philosophy

The critical element Liker stresses when discussing Principle 10 is the importance of building strong teams that enhance and challenge individual performance and contribution. In the TPS, bottom-up management and employee empowerment are deep-seated enablers to how Toyota stimulates and promotes a culture based on problem solving that drives slow, steady, incremental continuous improvement.

To emphasize the importance of this trait of the TPS, Ken Kreafle, General Manager of Production Engineering, Toyota Motor Engineering and Manufacturing

North America (TEMA), an annual keynote speaker at The Boeing Company's Lean Enterprise Conferences (Fall and Spring), suggests the following when discussing Toyota's management values and beliefs: "[t]he foundation is based on the realization that there are more capabilities and capacity in the company's people than is actually being utilized."[7]

Kreafle's description (see Figure 3-7) of how Toyota's management and people work together to leverage and empower team success seems to be one of the hidden gems associated with understanding the Toyota Way and how the TPS has successfully pressed forward over the past sixty years.

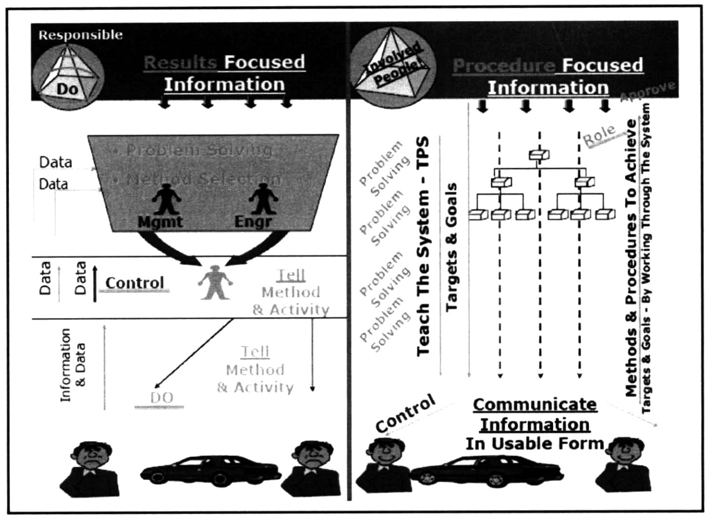


Figure 3-7: Ken Kreafle's depiction of Toyota Management and Team Member Engagement

Source: www.icbe.com

As noted earlier, the aerospace industry has a propensity to follow a very rigid top-down management approach. A serious consequence of this is that many of the root-causes of pervasive problems in the aerospace industry system tend to be buried deep within its roots. As a result defects get perpetuated and often times prevent the system from operating as though it were a well-oiled machine. In the TPS, if these same defects were to surface, the expectation would be that at the team level, members of the team would contribute to finding countermeasures to fix the immediate problems

[7] Kreafle, Ken. Key Note Speaker Address, The Boeing Company, Fall 2006.

that may arise and would then work over a longer period of time to eliminate the root-causes of the observed defects.

By contrast, the prevailing tendency within aerospace would be to engage in fire-fighting, putting a quick fix into place and never really working back to find the root causes of the observed defects in order to take them completely out of the system.

Principle 11: Respect Your Extended Network of Partners and Suppliers by Challenging Them and Helping Them Improve

Perhaps the most critical principle in relation to this thesis is Principle 11. However, this should be taken with some caution, since, as we have seen, the management principles within Toyota are explicitly intertwined with one another as an interdependent web. With Principle 11, Liker reinforces Toyota's willingness to enhance and cultivate the system, rather than look for short-term quick fixes. In aerospace, such quick fixes would be seen as a means of achieving quick financial gains and would hence receive a high degree of attention. This is in contrast with Toyota's longer-term focus, which is ultimately oriented towards developing a learning extended enterprise.

To underscore this point, Liker uses a modified Maslow Needs Hierarchy to describe Toyota's treatment of its supply chain partners. The hierarchy's five levels include (from the bottom up, see Figure 3-8):

1. Fair and Honorable Business Relations
2. Stable, Reliable Processes
3. Clear Expectations

4. Enabling Systems
5. Learning Enterprise

In applying this philosophy, Toyota is not driven by a desire to drive towards achieving lowest price or implementing a competitive bid with its partners. Liker also emphasizes that Toyota does not cut its ties with suppliers when they end up generating errors or defects in the system.

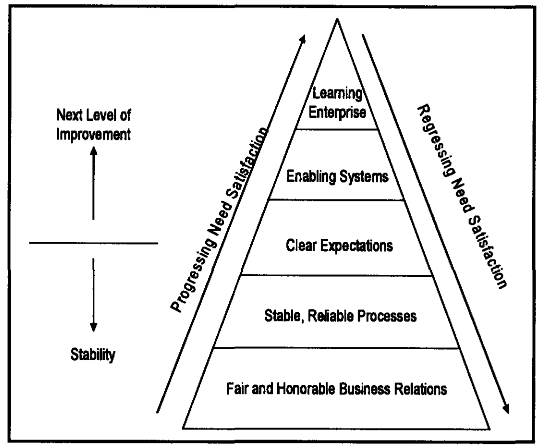


Figure 3-8: Supply Chain Need Hierarchy

Source: Liker (2004, p. 215)

One method Toyota uses to assist suppliers is through associations that suppliers may join to improve their understanding and implementation of TPS. In these organizations, suppliers attend study groups to share their experiences in implementing TPS. This concept includes the use of cross-functional design teams with a goal of optimizing cost, manufacturability and quality, employing an iterative design approach. This is a point that will be explored in greater detail later as part of the discussion of Toyota's product development practices and partner collaboration techniques.

Certainly, aerospace has quite a long way to go in order to achieve the level of collaboration Toyota has successfully established with its supplier partners. For example, when publicly speaking about the six month production slide associated with the 787, Boeing's Mike Bair, former Vice President and Chief of the 787 Program was quoted as saying the following pertaining to partners supporting the program: "[s]ome of them proved incapable of doing it" (Gates 2007). Bair expressed frustration that some partners seemed "unwilling, for whatever reason" (Gates 2007). "They just didn't do what we thought they could do, who knows why" (Gates 2007)?

In his public comments expressing his frustration with Boeing's supplier partners, Bair does not seem to mention anything specific about the possibility that Boeing, as the primary system integrator with responsibility for the entire program, may not have provided sufficient oversight of the performance of its supplier partners. While Bair's comments would appear, to an external observer, to be rather critical of Boeing's supplier partners supporting the 787 program, it is worth pointing out that Boeing, for reasons it found important, took a historic and significant leap forward in collaborating with its supplier partners, breaking a long-established top-down "build-to-print" tradition. This is not, by any means, meant to exonerate what may have been certain shortcomings in Boeing's oversight responsibilities concerning the capabilities, processes, practices and performance of its worldwide supplier base reaching down to lower-tier suppliers. Hence, before suggesting that Boeing could probably have done better in managing its supplier base supporting the 787 program, it is worth considering the following passage that Liker highlights in association with Principle 11, which specifically outlines some of the harsh approaches utilized by Toyota under Taiichi Ohno's tenure (Liker 2004, p. 211):

> Toyota's suppliers' Jishuken in Japan is completely different from that in the U.S. It is compulsory. You cannot say no. Toyota picks suppliers to participate. From each supplier they pick three to five members. Toyota sends their own TPS expert to the target plant and they review this plant's activity and give a theme, e.g., this line must reduce 10 people from the plant. The supplier's member has one month to come up with a solution. The TPS expert come back to check to see if the supplier has met the target. Then the Toyota TPS expert verbally

abuses the supplier participants. In the past some of the participants had a nervous breakdown and quit work. Toyota has a gentler version on TPS in the U.S. Once you clear Toyota's jishuken in Japan, you can feel so much more confidence in yourself. One of the former Trim Masters presidents went through this and became so confident he never compromised anything with anybody.

In summary, Mike Bair's comments point out the possible difficulties that are likely to arise in attempting to bring together and integrate a global extended enterprise value stream in designing and developing a major new commercial aircraft. Evolving common expectations throughout the value stream across multiple cultural boundaries, while supporting and cultivating a global supplier base, is arguably a daunting task. It is well worth remembering that it took Toyota quite a long time to build a lean supplier network and learn the lessons of this very principle. It is not surprising, then, that it might take some time for Airbus and Boeing to grow the same type of collaborative relationships with their respective industry partners.

Principle 12: Go and See for Yourself to Thoroughly Understand the Situation (Genchi Genbutsu)

With Principle 12, Liker emphasizes the necessity for management and engineers to go to the factory floor, the place where the product comes together to see and learn. Through this process, Genchi Genbutsu – (Liker 2004, p. 224) "translated in Toyota to mean going to the place to see the actual situation for understanding," allows for engineers and managers to observe and fully understand the situation associated with the products they are responsible for producing. When they observe opportunities to make improvements, then they utilize team-based skills and learning to enhance, test and make the required improvements. For example, Taiichi Ohno, who many consider the main architect of the TPS, was instrumental in defining ways to identify waste. One process that he promoted was to simply stand in one location and watch the processes being performed. By simply watching, employees could see, learn, and note methods to remove wasted processing. A wonderful example of this practice was captured in *Learning to Lead @ Toyota*, by Steven J. Spear.

Spear outlines in the article the maturation of an executive candidate brought into Toyota, who is subjected to an extensive set of hands-on learning experiences, to enable that person to learn directly from observations on the factory floor. Spear writes (Spear 2004):

> Throughout Dallis's training, he was required to watch employees work and machines operate. He was asked not to figure out why a machine had failed, as if he were a detective solving a crime already committed, but to sit and wait until he could directly observe its failure – to wait for it to tell him what he needed to know.

The key learning captured in this article was Dallis's participation in Genchi Genbutsu. When visiting one of the two OEM airplane manufacturers and or their suppliers, rarely are engineers or executive leaders seen on the manufacturing floor. Typically, senior executives only travel to the manufacturing floor for customer roll-out ceremonies or events associated with major milestones for a particular airplane program. Within Toyota it is understood that some very senior executives are not able to practice Genchi Genbutsu on a regular basis. As a result, they make use of trusted advisors that provide detailed summations from their observations performing Genchi Genbutsu. This process is known as Hourensou. Even though the concept exists and the CEO of Toyota uses it, the CEO still goes to the manufacturing floor to see and learn. Liker stresses that everyone in Toyota is expected to stay in touch with the value-added process of manufacturing the end product.

Principle 13: Make Decisions Slowly by Consensus, Thoroughly Consider All Options; Implement Rapidly

Principle 13, which provides Toyota a distinct competitive advantage against its competition in the automotive industry, directly correlates to some of the largest management shortcomings within with the aerospace industry. Within Toyota, the goal is never to make a rushed, ill-thought-out decision. Liker repeats the importance of this concept throughout *The Toyota Way*, periodically using the analogy of the tortoise and the hare. In fact, the analogy should be attributed to Taiichi Ohno and Shigeo Shingo, both referencing the analogy throughout their writings pertaining to the TPS, and both underscoring the importance of making steady, methodical, decisions based on the consideration, examination and simulation of many options when making decisions, by following a process known as Nemawashi (Liker 2004, p. 241). "When we support your (Boeing) kaizen workshops, you are challenged to develop seven ways to make process improvements; Mr. Ohno would challenge us to observe the process and develop hundreds of ways to improve a process, always thinking without our wallets."[8] The previous quote from Sensei Niwa, Chairman of Shingijutsu Global Consulting USA, reinforces the importance of observing, experimenting, and never rushing to make an ill-

[8] Niwa, Senji. Chairman, Shingijutsu Global Consulting USA Inc. Speaking at BAE, 2003.

thought-out decision. Liker also reinforces the point that once a decision is made in Toyota, it is implemented quickly.

One of the biggest constraints to producing significantly larger volumes of commercial aircraft annually in the aerospace industry is the substantial capital investment required for fixed tooling, also known as rate tooling. Since the aerospace industry is extremely cyclical, these highly capital-intensive tools are utilized at full operating capacity only rarely. Sadly, even if the OEMs are operating at full production rate capacity, it does not mean that the tools are being used in an optimized fashion. This is because the tools are designed for static build processes, which means that an airplane unit has multiple processes worked on it at the same time while it sits at a given station marking a fixed tool location. As it is pointed out quite often in this thesis, often times waste becomes hidden and entrenched in processes when the product is not built to specific flow requirements. With the advent of moving line technology in aerospace, involving specifically Boeing's 737 and 777 Airplane Programs, flexible, flow-based production became possible, immediately surfacing waste that had been hidden in traditional static based operations. Along the way, Boeing carefully had to examine and make thoughtful decisions when implementing the moving lines. Both moving lines are still in their infancy compared to those at Toyota. Their creation and the benefits they produce clearly reinforce Toyota's approach to decision-making as highlighted by this principle.

To help understand Toyota's decision-making processes, Liker highlights the following decision parameters, all of which are scalable to, and would benefit, the aerospace industry (Liker 2004, p. 239):

1. Finding what is really going on, including Genchi Genbutsu.
2. Understanding underlying causes that explain surface appearances – asking "Why?" five times.
3. Broadly considering alternative solutions and developing a detailed rationale for the preferred solution.
4. Building consensus within the team (multi-functional), Including Toyota employees and outside partners.
5. Using very efficient communication vehicles to do one through four, preferably on side of one sheet of paper – Toyota utilizes an A3.

As Sensei Niwa highlighted to me, the concept of "try-storming"[9] multiple solutions to eliminate waste is depicted in the process of observing and experimenting to find a set of alternative solutions. This process generates a richer set of possible solutions and is in direct contrast with seeking point-based solutions. An example of the latter is the use of rate tooling in aerospace, which does not allow the ability to find and implement better solutions.

Principle 14: Become a Learning Organization Through Relentless Reflection (Hansei) and Continuous Improvement (Kaizen)

Principle 14 outlines the importance of creating a learning organization. As we have seen with previous principles, this particular principle is intertwined with, and dependent upon, the adoption of the various other principles. One of the key points that Liker discusses is Hansei, which in Japanese culture simply means reflection. Hansei is a Japanese method of reflection that Toyota recently has begun to teach and utilize with managers working outside of Japan. "It is one of the most difficult things they have ever had to teach, but it is an integral ingredient in Toyota's organizational learning" (Liker 2004, p. 257). The process involves looking at everything that one does and examining it for what could have been done better. With this self-reflection, Toyota utilizes a specific problem solving technique to improve the system.

The general problem solving technique Toyota uses (see Figure 3-9) includes the following steps (Liker 2004, p. 256):

1. Initial problem perception
2. Clarify the problem
3. Locate area/point of cause
4. 5-Why? Investigation of Root-Cause
5. Countermeasure
6. Evaluate
7. Standardize

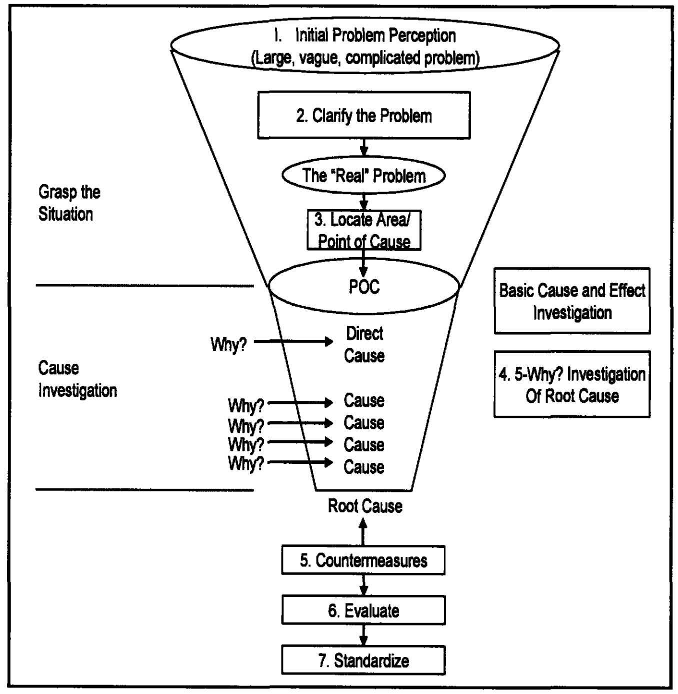


Figure 3-9: Toyota's Practical Problem Solving Process
Source: Liker (2004, p. 256)

It is noteworthy that it took Toyota a relatively long period of time to learn and internalize the concept of Hansei. Based on Toyota's past experience, it is quite likely that the aerospace industry has much to learn before being able to understand and implement the basic ideas driving this principle. Still, a major point that should be underscored here is that all 14 Management Principles captured by Jeffrey Liker in *The Toyota Way* are scalable to the aerospace industry.

[9] Shingijutsu Global Consulting USA Inc.

An Important Rebuttal from Georgetown

While conducting my research for this thesis, I came across this interesting review of Jeffrey Liker's, *The Toyota Way*, on Amazon.com. The review is in direct response to Liker's book from a Toyota employee based out of Georgetown, KY. The review is detailed as follows:

> I work at TMMK in Georgetown. With management's and the author's permission I personally wrote a detailed critique of Dr. Liker's book back in Sept. 2004 and to date, 12 months later, not a response from anyone.
>
> Dr. Liker's book is well written, but it includes several key errors which, if omitted, would make the foundation of his thesis weak. So, here we are a year later and just this past week Toyota announced a major recall of 978,000 vehicles. That number is equivalent to 2 full years of production at the Georgetown facility, though it should be noted that those vehicles being recalled were not produced at TMMK.
>
> Regardless, they are still Toyota vehicles and one has to wonder how does The Toyota Way address this quality failure? Think about it folks - 978,000 customers of Toyota purchased a problem they didn't anticipate, didn't want, but now have to devote time and energy to resolve.
>
> In my critique, I advised Dr. Liker that this sort of calamity was inevitable - perhaps in the next edition he will revise his assessment of Toyota. Just this past week, Rick Popely and Jim Mateja, reporters for Knight Ridder News Service, addressed the very problem that Toyota and Ford have created for themselves by sharing drive-train components and platforms among several models; with the downside being that when there is a problem, a lot more vehicles are affected.
>
> It's a cost-cutting measure which, both Ford & Toyota are willing to employ in order to increase profits. My question is this: Will Dr. Liker address this recall, and prior ones, as he attempts to praise Toyota's Way? Listen folks, the 14 principles Dr. Liker details are great and I encourage any organization to follow them, because for the most part, they will produce great results. My point on this book is that the reader is being led to believe that the modern day Toyota applies these principles. That's simply not true; otherwise they wouldn't be forced to fix 978,000 vehicles.

Those 14 principles work great, as they did nearly 60 years ago when Toyota Motor Corporation first began producing cars. Please don't misunderstand me - TMMK and Toyota as a corporation does a reasonably good job and I personally own 2 Toyota's, a 2001 Corolla and 2005 Sienna. The fact that TMMK allowed me to contact the author and explain my concerns speaks volumes for the company's willingness to become a better organization. I like the company and my job as a Team Member - I simply speak up to make it a better company than it is - and I told Dr. Liker his best source for reality is to spend more time on the floor and in the trenches than in the boardroom.

Well written book, but it's not the Toyota I know.

Team Member in Georgetown

Source: Farmer, Michael. September 14, 2005. *A Misleading Book*. Amazon.Com, Book Review – *The Toyota Way*.

Interestingly enough, when I visited Toyota's Georgetown facility in August 2006, our Boeing team asked our hosts about the recalls that Mr. Farmer highlights above. Not dodging the question at all, our hosts explained that while the recall rate was extremely high and something the company was not proud of, Toyota responded immediately to work with its partners to support the recalled vehicles through its services organization, acting much faster than its competitors typically would under similar circumstances.

Decoding the DNA of the Toyota Production System

Long before Hino and Liker wrote their respective books, Steven Spear and H. Kent Bowen provided a glimpse into how Toyota operates as a company with the article, *Decoding the DNA of the Toyota Production System*. The article's importance is very relevant to the argument that the TPS is indeed very much scalable to the commercial aerospace industry and would support transformational change throughout the system.

Spear and Bowen predominantly focus on Toyota's approach to the scientific method, supporting much of Hino and Liker's writings, and, in doing so, they outline four rules that make-up the essence of Toyota's system. The relevance of these four rules is that they not only mirror and buttress the set of principles, practices and tools associated with the TPS but also emphasize the importance of examining the TPS holistically.

The four rules that Spear and Bowen highlight focus on:

1. How people work
2. How People connect
3. How the production line is constructed
4. How to improve

The first three rules are associated with design, while the fourth focused on improvement. The authors argue that (Bowen and Spear 1999, p. 98):

> The Toyota Production System and the scientific method that underpins it were not imposed on Toyota – they were not even chosen consciously. The system grew naturally out of the workings of the company over five decades.

If this is indeed the case, and if one or both of the two aerospace giants were to adopt the TPS, then they would need to take ownership of how these principles are to be defined, communicated, and taught within the system to ensure that they ultimately become learned traits over a period of time engrained in the DNA of either one or both companies. To understand this point, we will examine the four rules briefly.

Rule 1: How People Work

Rule 1, detailed below, concerns the amount of detail and understanding Toyota employees are expected to master as part of a learning organization. Through the process of observing how work is performed, standard work is sequenced into intricate processes that are defined. If for any reason work is performed out of sequence, such an abnormality would immediately trigger an indication that something is wrong. For instance (Bowen and Spear 1999, p. 99),

> [C]onsider how workers at Toyota's Georgetown, Kentucky, plant install the right-front seat into a Camry. The work is designed as a sequence of seven tasks, all of which are expected to be completed in 55 seconds as the car moves at a fixed speed through a worker's zone. If the production worker finds himself doing task 6 (installing the rear seat-bolts) before task 4 (installing the front seat-bolts), then the job is actually being done differently than it was designed to be done, indicating that something must be wrong.

I'll never forget the experience of standing on the production floor in the Georgetown plant and watching two of the Toyota team members install an engine in less than 55 seconds into a Camry as it passed through their work zone. What immediately resonated with me when I saw this process was not the shock of the actual installation time but rather the intricate relationship Toyota has with its supply chain partners, where these suppliers, with Toyota's help, have developed the capability to design and build the components and systems they provide for easy alignment, integration and installation in Toyota's assembly process. How Toyota works with its suppliers in the design process is explored in more detail later in the thesis.

Spear and Bowen highlight Toyota's efforts working with a supplier to ensure the rule of defining how people work is defined (Bowen and Spear 1999, pp. 99-100):

> At one of Toyota's suppliers in Japan, for example, equipment from one area of the plant was moved to create a new production line in response to changes in demand for certain products. Moving the machinery was broken into 14 separate activities. Each activity was then further sub-divided and designed as a series of tasks… as each of the machines was moved, the way the tasks were actually done was compared with what was expected according to the original design, and discrepancies were immediately signaled.

Furthermore, Shigeo Shingo captures the essence of how valuable the implementation of standard work operations can be (Shigeo 1989, p.147): "the Toyota Production System trains new employees to work independently in three days; standard operating charts play a major role in making this possible." Utilizing this approach offers employees the opportunity to reference documented standard work sheet that outline the operations they are intended to perform. The importance of standard work, which Shingo as well as Spear and Bowen point out, is that through its creation, employees are expected to work to the standard, and if any variation surfaces, then experimentation is conducted to get the process sequence right.

The utilization of standard work practices in the aerospace industry could significantly be improved. It is important to point out, in this connection, that the level of standard work Toyota has been able to achieve is best optimized when design and manufacturing processes are integrated to leverage design for manufacturability and assembly (DFMA). We will examine this point further in Section 3.3 of the thesis, focusing on Toyota's Product Development Practices.

Rule 2: How People Connect

By means of Rule 2, Spear and Bowen specify the importance of supplier-customer relationships. Again, looking back at my visit to the Georgetown facility, it was evident that Toyota had mastered the relationships among the members of the various teams. When observing the company's internal part distribution processes, it was noteworthy that timing was down to the second. Spear and Bowen outline (Bowen and Spear 1999, pp. 99-100): "[l]et's return to our seat installer. When he needs a new container of plastic bolt covers, he gives a request to a materials handler, who is the designated bolt-cover supplier." The critical point in this relationship is that it allows for direct two-way communication and cooperation to take place. In traditional manufacturing operations, including aerospace, companies devote a substantial amount of resources to coordinating people, but the connections generally are not so direct and remain largely unambiguous.

Because the team members at Toyota operate in a direct manner, with specified times, the amount of variation that can enter into the process is limited. As seen with Rule 1, if variation begins to occur, work area leaders and management are brought to the point of concern to initiate countermeasures until the process is stabilized. Outside of Toyota, similar discrepancies would mount (Bowen and Spear 1999, p. 101) "by which time the cause of the problem may have been lost."

Rule 3: How the Production Line Is Constructed

As Liker outlined in *The Toyota Way*, production within Toyota is flow based. Therefore, with Rules 1 and 2 in place, Rule 3 allows for goods and services to flow directly to the right Toyota team member at a specific time within the sequence of an operation.

> To get a concrete idea of what that means, let's return to our seat installer. If he needs more plastic bolt covers, he orders them from a specific material handler responsible for providing him with bolt covers. That designated supplier makes requests to his own designated supplier at the off-line store in the factory who, in turn, makes requests directly to his designated supplier at the bolt cover factory's shipping dock (Bowen and Spear 1999, p. 101).

As with Rules 1 and 2, there is direct scalability of Rule 3 to the aerospace industry. However, without Rules 1 and 2 in place, achieving Rule 3 would be nearly impossible. It can be contended that the rules associated with how the TPS is operationalized on Toyota's manufacturing floor embody many of the same positive, mutually-complementary, interdependencies characterized by the 14 Management Principles that Liker discusses in *The Toyota Way*.

Rule 4: How to Improve

As already emphasized, Toyota epitomizes the essence of a learning organization. Rather than focusing specifically on Rule 4 as outlined by Spear and Bowen, it would be instructive to take a closer look at what the authors discuss pertaining to Toyota's

Commitment to Learning, a feature included in the article *Decoding the DNA of the Toyota Production System.*

> To reinforce the learning and improvement process, each plant and major business unit in the Toyota Group employs a number of Toyota Production System consultants whose primary responsibility is to help senior managers move their organizations toward the ideal. These "learner-leader-teachers" do so by identifying ever more subtle and difficult to solve problems scientifically.
>
> Many of these individuals have received intensive training at Toyota's Operations Management Consulting Division (OMCD). OMCD was established in Japan as an outgrowth of efforts by Taiichi Ohno – one of the original architects of the Toyota Production System – to develop and diffuse the system throughout Toyota and its suppliers. Many of Toyota's top officers – including Fujio Cho, honed their skills within OMCD. During their OMCD tenure, which can extend for a period of years, Toyota's employees are relieved of all line responsibilities and instead are charged with leading improvement and training activities in the plants of Toyota and its suppliers. By supporting all of all of Toyota's plant and logistical operations in this way, OMCD serves as a training center, building its consultants' expertise by giving them opportunities to solve many difficult problems and teach others to do the same. (Bowen and Spear 1999, p. 103)

As with Hino's and Liker's writings pertaining to Toyota, Spear and Bowen capture and outline fundamental beliefs and principles associated with the TPS. These three contributions, taken together, provide the foundation and architecture that could provide competitive advantage to either Airbus or Boeing if they were fully committed to adopting and implementing the TPS. While both companies have adopted tools and practices employed through TPS, neither will ever capture the full benefits that could significantly transform their systems. One can only imagine the possibilities and opportunities available to them for achieving significant performance improvement by taking a holistic approach to managing, cultivating, and stimulating a learning organization approach in their systems. In the following sections we will examine how Toyota has successfully extended its guiding values, principles and rules into its supplier base, truly optimizing holistic system performance throughout the company's value stream.

3.2 Overview of Toyota's Supply Chain Architecture

According to Charles H. Fine, Professor of Management at MIT's Sloan School of Management, Toyota's supply chain architecture is integral. By this, Fine means that the modular-integral distinction in product system architecture can be extended to describe the supply chain architecture, where integral architecture is defined along four dimensions of "proximity" between the customer company and its suppliers: geographic, organizational, cultural, and electronic (see Fine 1998, pp. 136-140). "Integral supply chain architecture is characterized by strong cross-company links and relatively high barriers to entry for newcomers" (Fine 2005). Members of the chain are close to one another in proximity, organizational alignment, and share cultural similarities. Toyota is well known for its ability to work collaboratively with suppliers. In fact, in Japan, Toyota typically has some type of financial stake in its strategic and or tactical supply chain partners. Fine writes (Fine 2005):

> As part of this relationship, many of Toyota's key suppliers are situated near the automaker's engineering and development operations in Toyota City, midway between Tokyo and Osaka. And with this geographical, social, and cultural proximity among Toyota and its suppliers, there is continuous bidirectional feedback on vehicle and subsystem design. One important example of this cozy partnership: Toyota engineers spend a great deal of time working at supplier sites to ensure that subsystems and components deliver the high level of integrality that the Japanese automaker demands for its vehicles.

Toyota does not only craft this type of integral relationship with its Japanese supply chain partners. Toyota's supply chain architecture parallels the company's globalization precept. Toyota strategically has cultivated its supply chain relationships in the countries it conducts business. For instance, in its North American business dealings, Toyota has stressed internal (domestic) production of parts being built within the United States, Canada, and Mexico, so that nearly 70% of the materials and components integrated into its products' designs are home-grown; when Toyota first began producing cars in North America, it was still importing roughly 70% of its parts from Japan to support production.[10] This type of growth can be attributed to Toyota's no nonsense approach to optimizing and leaning-out business practices, eliminating waste and reducing process related costs. For instance, would there be more efficiency in transporting products internationally as a global company, with Toyota's primary source for parts distribution residing in Japan, or would it be more efficient to grow localized supply chain and distribution channels in the countries where the company produces products? The answer is simple; developing a localized supply-chain with supporting distribution channels is seen as a far more advantageous approach from both a business and branding perspective.

It is instructive to review quickly the impressive growth in sales Toyota has achieved by building its North American operations, including the development of its localized supplier network. As stated earlier, when Toyota began its "transplant" operations in North America, nearly 70% of all the parts and components it needed

[10] Toyota Benchmarking Session, Georgetown, KY. August 2006

were still produced in Japan. However, through localization and the supplier base Toyota is now (Bowman 2000):

> [S]ourcing parts from about "300 suppliers, 70% of whom are located in the United States. Despite the distances involved since these suppliers are widely spread geographically, inventory consists mostly of products in motion. Toyota typically plans for only a few hours of safety stock, which might be increased somewhat during the winter months or when a supplier is located farther away from Toyota's assembly plants.

In the United States alone, Toyota's prowess to incrementally grow its supply chain has been critical to its impressive growth throughout North America. Toyota has been able to develop its domestic supplier network with the speed necessary to support its business growth ventures in the United States. Without a doubt, this has also helped Toyota with its brand recognition. In terms of Toyota's growth in the United States, it is well worth considering its growth from 1990 to 2006 in such areas as: 1) Vehicle Sales, 2) Production Growth, 3) Employment, and 4) Investment (see Figures 3-10 – 3-13).

While the numbers speak for themselves, Toyota has done a masterful job developing two facets of its supply chain architecture in the United States. First, in the spirit of Taiichi Ohno, Toyota has optimized its logistics practices throughout the United States so that inventory being shipped throughout the country is kept to an absolute minimum. "The closest thing to

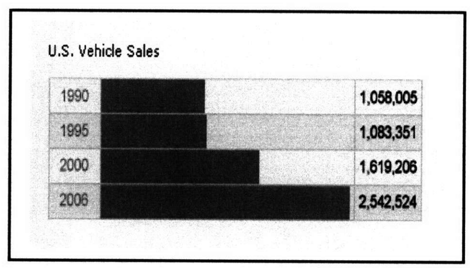


Figure 3-10: Toyota Vehicle Sales 1990 – 2006

Source: www.toyota.com

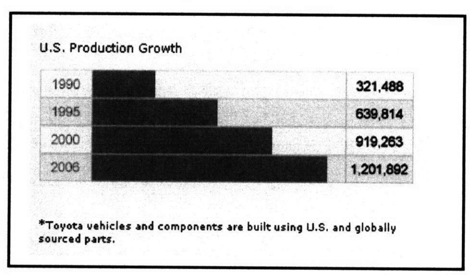


Figure 3-11: Toyota Production Growth 1990 – 2006

Source: www.toyota.com

a warehouse in the TPS system is a pair of cross-dock facilities in Kentucky and Michigan" (Bowman 2000).

Second, through its efficient logistics practices, Toyota has been able to create leveled and predictable ordering dynamics throughout its supply chain network in the United States.

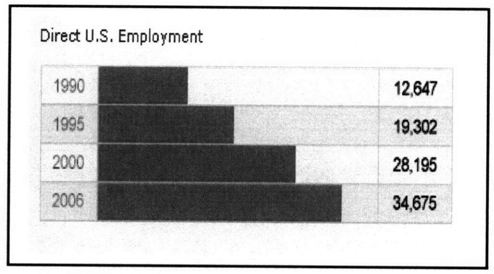


Figure 3-12: Toyota U.S. Employment 1990 – 2006

Source: www.toyota.com

A critical practice Toyota has been able to leverage throughout its North American operations is the utilization of cross-dock facilities (see Figure 3-14). These cross-dock facilities, which are located in Michigan and Kentucky, serve two primary functions: 1) they yield higher truck trailer loads, and 2) they increase the velocity of throughput from sub-tier routes (less traveled trucking routes) to main routes. The benefits provided through the cross-dock facilities are that they reduce costs and lead-times associated with shipping parts from

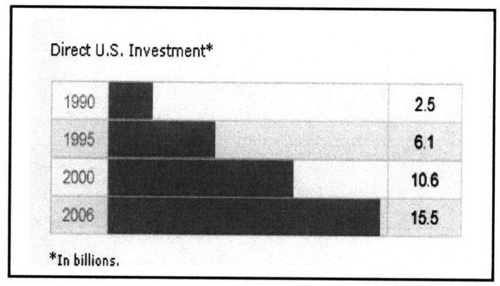


Figure 3-13: Toyota U.S. Investment 1990 – 2006

Source: www.toyota.com

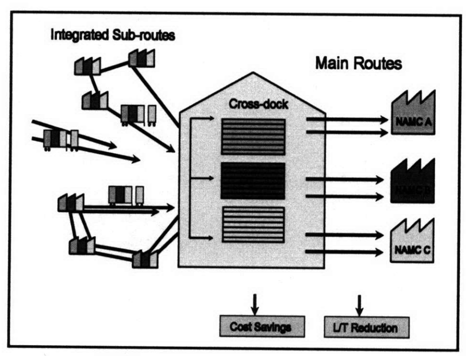


Figure 3-14: Toyota Cross-Dock Depiction

Source: TEMA Logistics

Toyota's suppliers. The impressive performance results Toyota's North American supply chain operation has been able to realize are highlighted below (source: TEMA Logistics):

- ~$500 million parts logistics budget in North America;
- ~500+ suppliers in the United States, Canada, and Mexico;
- ~2000+ trucks per day, ~800,000 miles per day Toyota-wide;
- 11 Toyota plant customers in Network;
- 5 core carriers (shipping partners);
- 2 core consolidation companies (third-party logistics providers);
- All oversight from TEMA, centralized design for plants and logistics since 2001.

The net result from Toyota's integral supply-chain architectural design is that the company's part ordering (system) dynamics are stabilized and predictable for suppliers supporting the company's production sites. Just as Toyota's team members work to takt time, Toyota's suppliers are able to produce and distribute parts at a specific pace. These dynamics can be easily seen through the simple example of The Beer Game, developed at MIT's Sloan School of Management by John D. Sterman.

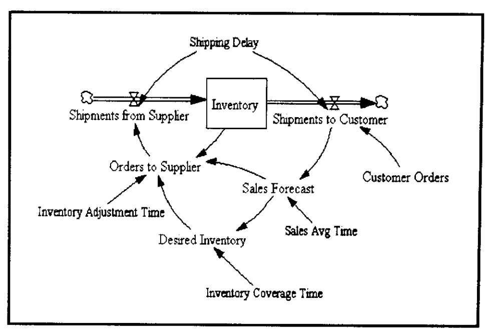


Figure 3-15: Inventory Distribution Chain – Single-Tier Model

Source: The Beer Game – Matthew Forrester, AT Kearney

Examining a traditional supply chain, single-tier model (see Figure 3-15); we examine the relationship between key variables taking place in the system. On the far right side, customer orders arrive and are filled from inventory. Orders to the supplier are based on a sales forecast, paced by a production master schedule, plus a fraction of the difference between desired inventory and required inventory. After a delay in the system, the order comes in as a shipment from the supplier. This particular model works well as long as no variation occurs in the production master schedule; if a fluctuation of orders occurs, causing a deviation to the normal schedule, the model's output will easily fall off of its equilibrium path (see Figures 3-16 and 3-17).

"A single stage in the distribution chain creates "amplification", that is, the orders it places with the next stage are more volatile than the orders it receives; amplification is the root of the "whip saw" effect where manufacturers experience much more a fluctuation than retailers."[11] More often than not this is referred to in the manufacturing industry as causing bull-whip effects in the supply chain, where an inventory shortfall increases shipment requests, ultimately causing a significant bottleneck to delivery performance.

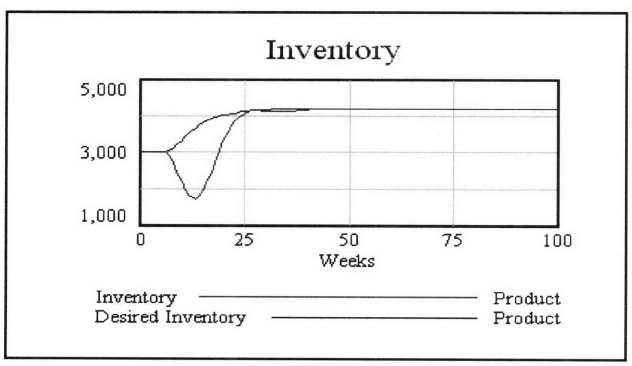


Figure 3-16: Inventory – Single-Tier Model

Source: The Beer Game – Matthew Forrester, AT Kearney

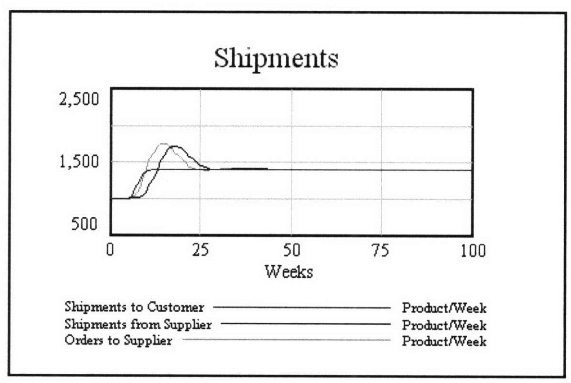
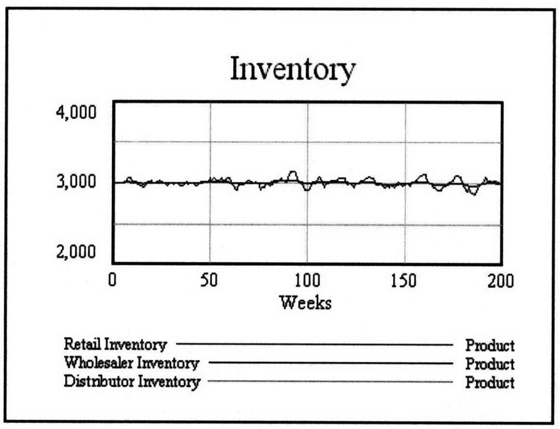
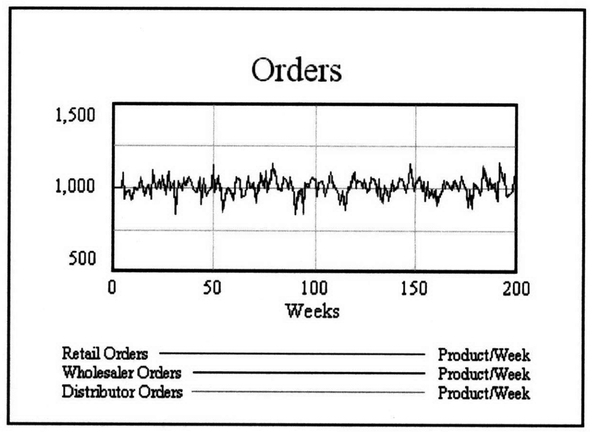


Figure 3-17: Shipments – Single-Tier Model

Source: The Beer Game – Matthew Forrester, AT Kearney

What differentiates Toyota's supply chain distribution practices from its competitors is that Toyota makes the required inventory needed visible to its suppliers, so that the suppliers can level their inventories. This concept is known as Vendor Managed Inventory. With Vendor Managed Inventory, "each stage of the supply chain ships an amount equal to the average retail sales plus a fraction of the difference between the sum of all desired and actual inventories downstream rather than responding to orders from the next lower level."[12] The levels of inventory the suppliers are able to maintain are then set with a minimum and maximum threshold so that no shortfalls or significant bull-whips occur throughout the order-based system (see Figures 3-18 and 3-19).





Figures 3-18 and 3-19: Inventory and Orders – Vendor Managed Inventory

Source: The Beer Game – Matthew Forrester, AT Kearney

Just as Toyota shares an integral relationship with its suppliers, it is just as important that it maintains an integral product development relationship with its partners. We will now examine the relationship and practices Toyota utilizes with its partners to develop its world renowned products.

[11] Forrester, Mathew. AT Kearney.
[12] Forrester, Mathew. AT Kearney.

3.3 Toyota's Product Development Practices

> Toyota's product development philosophy stresses the importance of cross-functional coordination for the development of most vehicle subsystems... and with geographic, social, and cultural proximity among Toyota and its suppliers; there is continuous bidirectional feedback on vehicle and subsystem design (Fine 2005).

Just as Toyota's supply chain management architecture reflects integral relationships, so does its product development practices. In fact, a well written article by Allen Ward, Jeffrey K. Liker, John J. Cristiano, and Durward K. Sobek II entitled: *The Second Toyota Paradox: How Delaying Decisions Can Make Better Cars Faster*, outlines that Toyota's product development processes give the company a distinct competitive advantage over its competition. It is well known that Toyota uses a process called "concurrent engineering" in its product development practices; however, so do most other auto producers and, for that matter, so do Airbus and Boeing in the aerospace industry. However, Toyota differs from its competitors that have implemented concurrent engineering through very prescriptive organizational designs.

> Toyota uses a relatively unstructured development process, its multidisciplinary teams are neither collocated nor dedicated, and, in the case of suppliers, Toyota communicates intensively about product development with a smaller portion of supply base than do U.S. auto companies (but Toyota suppliers give their customer higher marks for communication effectiveness than U.S. suppliers give their automakers) (Cristiano, Liker, Sobek II, and Ward 1995).

While the commonly known TPS associated with how Toyota manufactures its products is Toyota's first paradox, the second paradox is what the authors' reference as

(Cristiano, Liker, Sobek II, and Ward 1995, p. 44) "set-based concurrent engineering." Ironically, the authors' describe the second paradox in what would seem to most as inefficiencies in Toyota's processes, in brief, (Cristiano, Liker, Sobek II, and Ward 1995, p. 44) "delaying decisions, communicating "ambiguously," and pursuing excessive numbers of prototypes" working with its supply chain partners to ensure optimized integration of subsystem elements. A closer examination of the distinct relationship Toyota maintains with its supply chain partners during the product development process sheds more light on Toyota's product development practices.

Ensuring a high level of collaboration and precise communications with supply chain partners is absolutely critical to any type of product development initiative. It is well to keep in mind, in this context, the comments reported earlier by Mike Bair, the former manager of Boeing's 787 program. Toyota leverages long-term partnerships across its supply chain network, which carries over to its product development processes. Moreover, Toyota does not give equal design responsibility to its supply chain partners; rather it varies the nature and extent of design responsibility delegated to its partners based on their capabilities, by employing three distinct relationship categories. The authors' of *The Second Toyota Paradox: How Delaying Decisions Can Make Better Cars Faster* describe this relationship as follows (Cristiano, Liker, Sobek II, and Ward 1995, p. 54):

> The relationship level appears to be determined by the supplier's engineering capability, past performance record, complexity of the part, the degree to which the part interfaces with others, the stability of the technology, and so on.
>
> The first-level relationship is a partnership. This type of supplier greatly influences not only the detailed design of the parts it makes, but also the concept. Such suppliers do extensive development well before Toyota decides on its own

vehicle concepts, often presenting Toyota with a wide range of alternatives early in the process. Toyota may then choose one or more of the options.

The second-level, mature, suppliers wait for Toyota to define its needs for specific vehicle concepts before beginning development. However, they work with Toyota in a process that goes far beyond conventional negotiation to determine part specifications (including cost).

At the third level, which we call "parental," all the major decisions are made by Toyota, with little influence from the supplier. The supplier may design to specification or simply manufacture a Toyota design.

While Toyota's partner-level suppliers are typically working to produce innovative product changes well in advance of the product development cycle, most of the remaining level 2 and 3 suppliers are brought into the process 36 months before the product is put into production. At the 36^{th} month point, Toyota's suppliers show the most recent developments in their product/part designs that they could provide for incorporation into Toyota's new product offering going into development. Typically suppliers produce multiple options, simulate, test and down-select them so they can make specific design and technology recommendations to Toyota; "[t]he presentations include working prototypes and a great deal of test data, with comparisons to existing and/or alternative designs" (Cristiano, Liker, Sobek II, and Ward 1995, p. 56). Toyota is thus able to leverage the capabilities of its suppliers throughout the development process (Cristiano, Liker, Sobek II, and Ward 1995, p. 56): "before Toyota starts making decisions about the vehicle, or at least about detailed specifications, it is gathering supplier's information and data." To demonstrate the level of design integration Toyota has been able to master working with its suppliers, I would like to share some insights I captured while visiting the company's Georgetown, KY, production site. This particular example should outline the masterful output Toyota has been able to achieve, while leading the automotive industry in terms of the velocity of developing new products and doing so at substantially lower costs than its competitors. The following excerpt is taken from my notes during the benchmarking trip to Toyota's Georgetown plant:

> Pertaining to large scale system integration – Toyota's entire system is premised on the idea of flow, designed to support the flow of products throughout the production system – where the products themselves are designed in the first place to support the system's cadenced operation -- while ensuring worker ergonomics and safety as people smoothly go about carrying on their jobs transporting parts and performing their assembly tasks.
>
> What does this mean? Using the engine installation sequence as an example, the design of the engine takes into consideration the following implementation and integration points:
>
> - Dimension
> - Weight
> - Connection Points
> - Supplier (capability and location)
> - Packaging
> - Transportation
> - Load Sequence (multi-model line with different engine types)
> - Packaging
> - Shipment Route Optimization
> - Dock Transfer Process
> - Internal Routing
> - Line Placement
> - Installation
>
> In looking at this example, it forces the Design Engineers, Packaging Engineers, Procurement, Supplier Quality, Supplier Development, and Toyota's suppliers to be

focused on waste elimination at every integration point of the product's design through the system's processes – they all have to work together via large scale system integration.

By the time the engine is delivered to the production line, the two operators performing the installation have two decisions to make, which determines the installation sequence. Their decisions are controlled by visual controls, showing the car model type flowing into their work cell and the engine type they are installing.

We literally were able to see two operators maintain a takt time of 55 seconds to do engine installation with ease in a very ergonomically correct and safe fashion. This type of installation was evident throughout the assembly line – every assembly had an optimized design for manufacturability, not only from a product perspective, but also taking into consideration the detail integration elements, precise build sequence (leveled to align installation by cell), ergonomic, and support processes. All functions worked together via simulation at the integration points to streamline design and take waste out of the system, including collaboration with the supplier partners in the design process.

In addition to the criticality of learning more about Toyota's guiding precepts and management principles, I would contend that the greatest learning Airbus and Boeing could take away from Toyota pertains to the "second paradox". This paradox provides the key into understanding the unique competitive advantage Toyota is able to maintain in the auto industry pertaining to product development and also helps explain how the company works with its supply chain partners to create collaborative advantage.

3.4 Toyota's Unique Capability to Leverage Supplier Partnerships

Through the utilization of integral supply chain management and product development practices, Toyota has been able to create closely-knit relationships with its suppliers. These relationships have forged strong collaborative bonds that are built on the foundation of trust. Therefore, the relationships Toyota has been able to build with its suppliers have provided Toyota the opportunity to work well beyond its production floor to extend its practices associated with the TPS into its entire enterprise value stream. With more and more products getting outsourced to suppliers, whether in the automotive or the aerospace industry, organizational boundaries of the OEMs are no longer confined to their own "four walls" but rather extend widely into the enterprise value stream embracing a global supply chain. As a result, if one OEM can work with its partners in the supply chain to create a collaborative advantage against the competition, the successful OEM will most likely achieve improved product design integration, enhanced quality yields, better aligned inventory management practices, and, most importantly, reduced cost. In other words, the OEM and its suppliers will be well along the way to achieve "virtual integration" (Dyer 2000, p. 9). It is through this integration process that, "Toyota's tightly integrated extended enterprise – characterized by a high-level of dedicated investments, a high degree of knowledge sharing, and a high degree of trust – outperforms the loosely integrated production networks of its competitors" (Dyer 2000, p. 9). One of the key factors contributing to Toyota's success working with its supply chain partners is its utilization of supplier associations.

> Toyota's supplier association (kyohokai) in Japan was established in 1943 to promote "mutual trust" and the "exchange of technical information" between Toyota and its parts suppliers... in 1989 Toyota started its U.S. supplier association (Bluegrass Automotive Manufacturers Association, or BAMA) (Dyer 2000, p. 64).

Through its supplier associations, Toyota works with its parts suppliers to provide a forum to openly communicate with them and receive supplier feedback. Since 1989, BAMA has grown considerably and has many outlets for suppliers to participate within its structure (see Figure 3-20). Jeffrey H. Dyer, author of *Collaborative Advantage*, provides an excellent outline of how BAMA works at its different levels (Dyer 2000, pp. 66-67):

> The general assembly, top management meetings, and executive meetings are designed to allow for high level communication within the supply chain network with regard to production plans, policies, market trends, and other issues. Thus, these meetings are designed to share explicit knowledge among members. More frequent interaction occurs within the divisional committees and topic committees (cost, quality, safety, etc), where members engage in both explicit and tacit knowledge sharing. Divisional committees are comprised of suppliers who join the meetings because of the nature of the parts they produce or the production processes they employ.
>
> The topic committees on cost, quality, safety and general affairs are designed to facilitate knowledge sharing on subjects that are critical to all members in the extended enterprise.

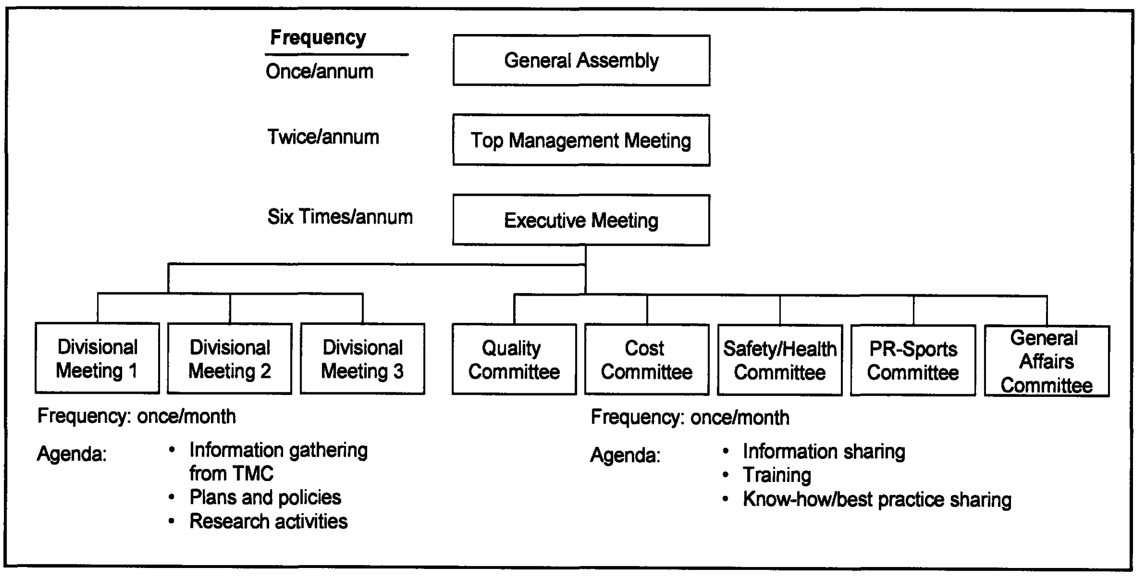


Figure 3-20: Organization of Toyota's Supplier Association Dyer (2000, p. 66)

It has taken decades for Toyota to cultivate and grow its supplier associations, with a distinctive purpose. The purpose of Toyota's supplier association is to stimulate communication amongst the company's suppliers so they can share information with one another. In addition, the supplier association forum allows for Toyota's suppliers to build relationships with the OEM and with other suppliers that produce like products. Thus, if a supplier producing one of Toyota's parts encounters a problem, it can extend a hand to another supplier for help, which means that Toyota's suppliers that are competitors actually help one another to keep the system moving; they act, in fact, as vested participants within Toyota's extended enterprise. As we have emphasized throughout the thesis, Toyota's utilization of its precepts extends well beyond the company's own "four walls," fully employing the concept of a learning organization throughout its entire value stream. Utilizing a far reaching collaborative forum through its supplier association, Toyota is able to collaborate with its partners, thereby giving the company a collaborative advantage over its competitors working with many of the same suppliers.

3.5 Toyota's Procurement Methods

We briefly examine here Toyota's procurement methods to convey a more comprehensive understanding of the company's supply chain management practices and round out the focused discussion on the Toyota Motor Corporation. We first recall Kiichiro Toyoda's ideal pertaining to cost. Rather than using the prevalent cost accounting techniques of the day, which stated Price = Cost + Profit, Kiichiro borrowed from Henry Ford's philosophy and established the precedence of looking at cost from the viewpoint that Profit = Price – Cost (Hino 2006, p. 8). When explaining the cost method and its importance, Taiichi Ohno lent a much more straightforward explanation (Ohno 1988, p. 9):

> [o]ur products are scrutinized by cool-headed consumers in free, competitive markets where the manufacturing cost of a product is of no consequence. The question is whether or not the product is of value to the buyer. If a high price is set because of the manufacturer's cost, consumers will simply turn away.

Many manufacturing companies use competitive bidding strategies to procure parts from suppliers. Within industry this practice often produces arms-length relationships because the focus of the relationship is based on cost. This is in sharp contrast with the practice of creating collaborative advantage and mutual trust between the OEM and its part suppliers. According to Dyer's research (Dyer 2000, p. 101):

> It (the research) shows that the competitive bidding process fosters mistrust and that automakers that aggressively use competitive bidding are always viewed as less trust-worthy. According to suppliers, the competitive bidding system immediately creates an adversarial relationship with the automaker because the exchange relationship is set up as a zero-sum game.

Consequently, the OEM conducting the competitive bidding process projects the predominant perception to its supply chain partners that it does not care about their profitability, overall health, or long-term existence. Hence, the OEM's parts suppliers are left without a sense of purpose, loyalty or sense of belonging as part of the overall system. This represents a substantial difference from Toyota's practices, as discussed above. As members of Toyota's supplier association network, suppliers demonstrate a sense of purpose within Toyota's value stream and are vested in working together to enhance overall value contribution to the system; even if this may mean at times working with others they may consider their competition.

As described earlier in discussing Toyota's product development processes (Section 3.3), Toyota does not utilize competitive bidding for the parts and components it obtains from its suppliers. Instead, Toyota selects suppliers based on their previous performance track record. Based on a supplier's part processing capabilities, performance, and Toyota's own knowledge of how the part could be produced at an optimized cost, Toyota communicates a target price to its suppliers. Cristiano, Liker, Sobek II, and Ward provide an excellent description of Toyota's approach to working target price with its suppliers (Cristiano, Liker, Sobek II, and Ward 1995):

> Along with target specifications for a component's space and performance, the customer (Toyota) gives suppliers a target price. This important difference between U.S. and Japanese companies has been discussed at length. In short, the automaker decides what price the market will bear for the total vehicle and works back, roughly allocating costs to major subsystems and components. It then gives that cost to the supplier as a target at the beginning of the design process. The supplier has great incentive to design the part so it can meet that price and still make a profit.
>
> There seems to be less flexibility in the target prices than in other component specifications, although suppliers show Toyota graphs of performance-weight-cost trade-offs and, in some cases try to sell Toyota on higher price to achieve better performance or lower weight. In the traditional U.S. system, suppliers design parts to specifications and negotiate price later, sometimes competing with suppliers that were not involved in product development. In the Japanese system, there is much greater opportunity to explicitly consider trade-offs between cost, performance, and weight in the early design stage, before commitments are made. As in other aspects of design, Toyota seems to be more flexible and waits longer to set a firm price than other Japanese automakers. Thus, to a degree, Toyota is using a more set-based approach to target pricing.

To take it a step further, if Toyota's supply chain partners cannot achieve the target price that has been established, Toyota will provide them consulting services to take wasteful steps and transactions out of the process so that the target price can be achieved. Dyer provides the following example of a supplier in the United States conducting business with Toyota.

> Toyota sent in a team of consultants to offer suggestions on how we could reduce our costs to meet the target cost. Their help was extremely valuable and we made some significant improvements. But after considerable effort we felt we would be unable to hit the target cost. So we visited the purchasing manager to ask for a price increase. After we made our request, the purchasing manager pulled out a file which had a list of the actions we were to take based upon the suggestions of their consultants. While pointing to the first item on the list, he asked, "Have you done this yet?" Fortunately we had and responded positively. But then he proceeded to go through each item on the list. We could only answer "yes" to about two thirds of the items. Then he said, politely, "When you have taken action on every item on this list you won't need a price increase; but if you still think you do, come back and we will discuss it" (Dyer 2000, pp. 77-78).

In order to transition to the target cost method, OEMs must have significant process knowledge to work with their suppliers to identify target costs. Essentially, Toyota knows detailed parts processing better than its suppliers. With this inherent knowledge, Toyota is able to set aggressive cost targets with its supply chain partners that are achievable. In the process, if Toyota's suppliers struggle to achieve the target costs that have been established, Toyota lends the suppliers help and guidance on how to achieve the targeted cost. The follow-through that Toyota demonstrates with its suppliers during this period also helps establish and reinforce trust. With the spirit of the learning organization instilled in its procurement practices, Toyota is able to achieve the cost focus Kiichiro Toyoda had established for the company. Furthermore, the company has been able to uphold the words of Taiichi Ohno (Ohno 1988, p. 9):

> Cost reduction must be the goal of consumer products manufacturers trying to survive in today's marketplace. During a period of high economic growth, any manufacturer can achieve lower costs with higher production. But in today's low-growth period, to achieve any form of cost reduction is difficult.
>
> There is no magic method. Rather, a total management system is needed that develops human ability to its fullest capacity to best enhance creativity and fruitfulness, to utilize facilities and machines well, and to eliminate waste.

The Toyota Production System, with its two pillars advocating the absolute elimination of waste, was born in Japan out of necessity. Today, in an era of slow economic growth worldwide, this production system represents a concept in management that will work for any type of business.

4 AEROSPACE SUPPLY CHAIN ARCHITECTURE – DESIGN, STRATEGIES, AND PRACTICES

The commercial aerospace industry has changed significantly during the last sixty years. Perhaps one of the most significant transitions the industry has experienced pertains to the methods in which parts are procured and how the industry's supplier base has grown over time to become one of the most complex global networks of parts production and distribution known to any industry. After taking an extensive look at the precepts, management principles, supply chain design, product development practices, collaboration techniques and procurement practices that Toyota employs in working with its parts suppliers, a basic question that comes up is whether either one or both of today's commercial aerospace behemoths, Airbus and Boeing, can leverage Toyota's precepts, principles, and process methodologies to create the same level of success in the aerospace industry that Toyota has created and enjoys in the automotive industry.

Before answering this major question, it is important that we examine the evolution of supply chain management practices in the aerospace industry, by highlighting important recent developments. This discussion will serve as a preamble for examining The Boeing Company's 787 Dreamliner program and the revolutionary implementation effort it represents. In concluding this section, we will get to the core of this thesis, which is specifically concerned with an examination of the scalability of Toyota's supply chain management practices to the aerospace industry, to address the basic question of whether or not it is possible to transform the commercial aerospace supply chain management practices by utilizing Toyota's production system principles, practices, and methodologies.

4.1 The Evolution of Aerospace Supply Chain Management

During the post-World War II period aerospace supply chain management took place within the context of a high degree of vertical integration in the industry, even though not nearly as extensive as the Ford production system earlier in the century. Basically, OEMS acquired most of their hardware from in-house production. OEMs and their supplier base consisted mostly of their own wholly-owned business units and suppliers, as well as wholesalers and distribution systems they directly owned or controlled. Still, OEMs did procure some of their hardware from outside suppliers. In this system, people and paper were physically connected and controlled in all tiers of the supply chain by the OEM's centralized procurement operations. Although the OEMs controlled the information being transmitted throughout the system, there was often miscommunication between the different hierarchical levels in the OEM's value stream.

With economic and manufacturing growth taking place in the 1950s, the aerospace industry began to take a greater interest in supply chain management practices and methodologies. During this period, the OEMs realized some of the pitfalls associated with strongly aligned, vertically integrated, supply chain networks. Specifically, these pitfalls included "loss of high-powered incentives, loss of scale and access to outside customers, loss of strategic flexibility, and higher labor costs" (Dyer 2000, p. 53).

In the 1960s, the aerospace industry witnessed the birth of the first inventory management software systems, which carried over to the advent of Materials Requirements Planning (MRP) in the 1970s. MRP is a system that phases out the release of production and purchase orders to ensure that the flow of raw materials and in-process inventories matches the OEM's production schedules for finished products. The significance of MRP development was that it allowed OEMs to begin managing inventory electronically, rather than being completely dependent on paper-based management systems, thereby eliminating the manual coordination, integration, and alignment of the production of millions of detailed parts and their flow from the suppliers to the OEMs. During the late 1970s and early 1980s, the aerospace industry also took a major step forward with the development of The Boeing Company's 767 Airplane Program. The 767 was the first twin-aisle commercial airplane program to be comprised of a risk-sharing global network of participants with detailed design delegation and major structure build support taking place in the supply chain.

> Program participants were, in effect, risk-sharing partners who bore a portion of the costs of design, development, and tooling; major subcontractors were similar, but took on a smaller share of the work. Both were necessary because new airplane programs had become too big for Boeing, or any other single company, to handle alone. On the 767, Aeritalia, the Italian aircraft manufacturer, and the Japan Aircraft Development Company (JADC), a consortium made up of Mitsubishi, Kawasaki, and Fuji Industries, were the two program participants (Kerzner 2001, p. 538).

It will be recalled from an earlier discussion that during early stages of Toyota's product development process some key suppliers stay in residence within Toyota and, after a certain period, return to their home sites to conduct the remaining tasks required to support Toyota's design integration process. This can be compared to the process used by Boeing in developing the Boeing 767. Harold Kerzner provides a detailed account of the technology transfer approach Boeing utilized with its partners while developing the 767 (Kerzner 2001, p. 539):

> To begin, the Italian and Japanese participants were asked to work together with Boeing engineers. Engineering management helped to select the Italian and Japanese engineers that would participate in the 767 program, and rated them

according to their skill levels. The Italian and Japanese engineers then worked alongside Boeing engineers in Seattle. At the 25 percent structures release point (a critical milestone, at which point stress analyses had been completed), they returned to their home companies, accompanied by their Boeing engineering counterparts, who were then integrated into the Italian and Japanese engineering organizations. At the same time, in mid-1978, Boeing established residence teams in Italy and Japan, consisting of some of Boeing's best operations people. The operations teams evaluated and helped to establish participants' facilities, training, and manufacturing processes, and also certified their quality assurance processes. If problems arose, rapid communication with Seattle was often necessary; this was assured by a private telephone network connecting Boeing to each participant.

While the 767 program followed many of the same product development steps that Toyota utilizes in its set-based Concurrent Engineering process, Boeing followed the more traditional approach to perform Concurrent Engineering with its partners. Like many U.S. based companies, Boeing utilized its Concurrent Engineering techniques to compete with its competition, which at the time was McDonnell Douglas and a small European consortium, Airbus Industrie. Boeing's use of Concurrent Engineering was implemented, "largely through organizational design, creating highly structured design processes and multifunctional, often collocated, design teams, with intense communication among team members, including supplier engineers" (see Nevins and Whitney, p. 1-24). Although, Boeing did not use Toyota's practices, the 767 program did roll-out on-time in August of 1981 and only a couple of the initial deliveries of the airplane were delayed due to cockpit related design changes Boeing had to work-out with its customers, the Air Line Pilots Association (ALPA) and the FAA. Despite the enormous complexity of bringing together over three million plus parts, Boeing was able to hit its milestone type certification of the airplane, an accomplishment that can be attributed to the tightly- knit supply chain practices the company followed. As Fred Cerf, former Boeing Director of Systems and Equipment, observed (Kerzner 2001, p. 539):

> Generally, at Boeing we do not make contract with suppliers and then walk away. We feel responsible for them and have to make it work. This was especially true of the 767 program participants. Because the content of their work was so significant, a failure would have precluded our (Boeing's) ability to salvage an industrial operation of this size.

Through the next couple of decades, the commercial aerospace industry continued to leverage the supply chain in product development, the Boeing 767 program ushered the practice of leveraging the supply chain through risk-sharing arrangements with key suppliers. Later, Airbus Industrie utilized similar advances in supply chain management practices involving supplier participation in product development, involving its European consortium partners and suppliers. An important new development worth noting took place in the 1990s, when digital design techniques were introduced during the development of the Boeing 777. The use of digital definition transformed global collaboration efforts between Boeing and its supply chain partners, linking concurrent design integration efforts by bridging real-time Remote Digital Preassembly, Design Visualization, Digital Product Definition Release, and Digital Distribution Processes. Many of the technological design advances the 777 Program created were carried over to future derivative programs in aerospace, including the 777's use of carbon fiber application in the airplane's structural design.

During this same time period the face of the commercial aerospace industry also changed significantly. In 1997, McDonnell Douglas merged with Boeing to become The Boeing Company, and incrementally during the 1980s and 1990s Airbus Industrie transitioned from a comparatively smaller player in the commercial aerospace sector to become The Boeing Company's fiercest competitor. Airbus eventually supplanted Boeing with overall market share in sales in 1999 (see Figure 4-1), which catapulted the company to be the largest manufacturer of commercial airplane programs in 2001 (see Figure 4-2).

At the turn of the century, three of the four partner companies comprising Airbus Industrie, DaimlerChrysler Aerospace (Germany), Aérospatiale-Matra (France), and Construcciones Aeronáuticas SA (Spain) which is also known as CASA, merged to form the European Aeronautic Defense and Space Company (EADS). With this transition, EADS owned roughly 80% of Airbus Industrie and, shortly thereafter, BAE Systems and EADS transferred production assets to form, Airbus SAS, in return for a share of the company's asset holdings. With the formation of EADS and the merger of McDonnell Douglas and Boeing, there were now two major producers of large commercial aircraft, aircraft with more than 100 seats, supporting global commercial aerospace production requirements.

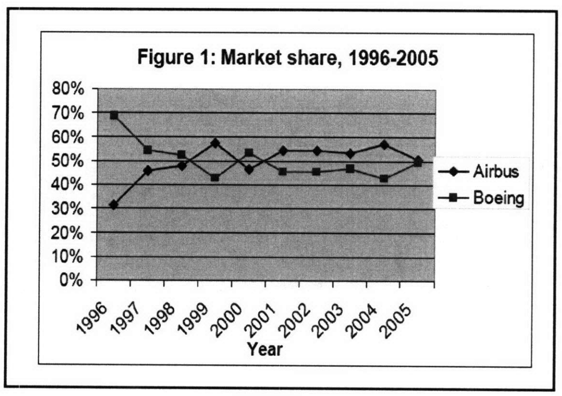


Figure 4-1: Aerospace Sales Market Share, Airbus and Boeing, 1996 – 2005

Source: I.P.L Png.

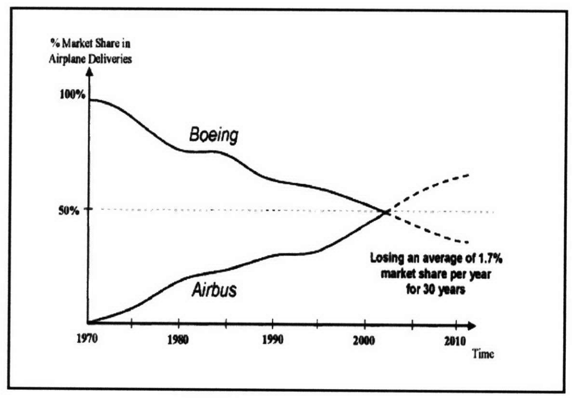


Figure 4-2: Aerospace Production Market Share, Airbus and Boeing, 1970 – 2010 (Forecast)

Source: Piepenbrock (p.46)

With the dramatic corporate consolidations and market share changes taking place in the aerospace industry during the late 1990s and at the turn of the century, there were also substantial transitions in supply chain management practices that shaped the relationships linking both Airbus and Boeing with their respective parts suppliers. Considering that the market outlook calls for $2.8 trillion in revenue generation during the next twenty years, of which a significant portion will involve fixed costs to be borne by the parts suppliers of both companies, neither Airbus nor Boeing can ignore the need to transform their supply chain management practices. The basic that remains is which of the two OEMs would take the next bold step, moving from the traditional supply chain management practices that had been crafted two decades earlier in support of Boeing's 767 Airplane Program derivative launch?

4.2 Recent Developments in Aerospace Supply Chain Management Practices

Soon after the turn of the century, the aerospace industry was rocked with two exogenous shocks, the events of 9/11 and SARS; both events dramatically reduced sales of commercial aircraft, which ended up having a significant impact on the supply chain design and management practices, particularly in developing new products. After the events of 9/11 and the SARS epidemic, Boeing Commercial Airplanes went through a large cyclical downturn, in the process laying-off over 30,000 employees. Simultaneously, Airbus was in the middle of its A380 derivative program, expending a high-level of intellectual and monetary capital to get the large double-decker airplane launched, designed, and off the ground. Both OEMs were crunched and put into the position of needing to reduce costs associated with their airplane programs. Without significant cost reductions the OEMs would not be able to support airline customers' demands for more affordable aircraft. As a result, Airbus and Boeing began to employ further collaboration and risk-sharing techniques to change their existing supply chain management methods. Some of the practices the OEMs began working with their supply chain networks included working enhanced logistics and distribution practices, transferring design delegation authority on specific commodities, and implementation attempts associated with large-scale systems integration of multiple parts and commodity packages.

Airbus had long used "Super Guppies" to transport large assemblies between its production facilities in France, United Kingdom, Germany, and Spain. Airbus began using the guppies in the early 1970s, using modified Boeing Stratocruisers that were originally produced in the 1940s. Because of inefficiencies associated with the older Boeing Stratocruisers, Airbus transitioned in the 1995s to create the new Beluga, A300-600ST (see Figure 4-3), to support moving parts more economically between the consortium's production facilities.

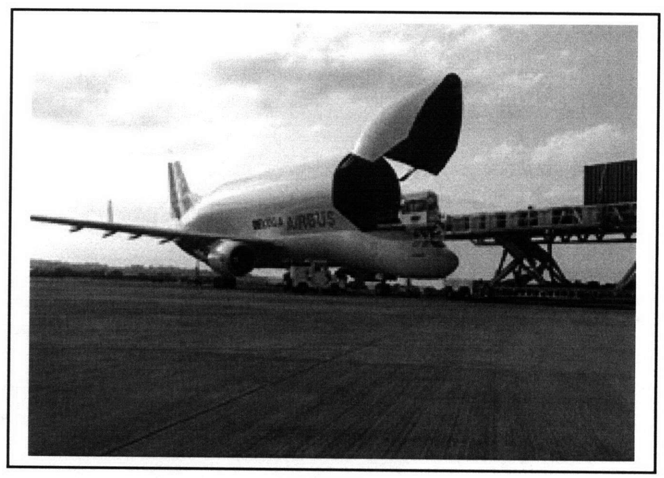


Figure 4-3: Airbus SAS Beluga, A300-600ST

Source: www.diseno-art.com

To respond to some of the new efficiency gains Airbus was demonstrating through the use of its Beluga, Boeing took action and began improving its logistics operations by shoring up its shipping, rail, and trucking practices. At the time, Boeing did not have an answer to airship its large assemblies. With its incorporation of leveraged logistics practices, Boeing also worked with its supply chain partners to improve

distribution processes.

Some of the concepts Boeing introduced to enhance distribution processes included point-of-use delivery, kitting, and an installment of "milk-runs" with local parts suppliers throughout the Puget Sound region.

In addition to working with its supply chain partners to improve logistics and distribution practices, Boeing began working with them to transfer design delegation authority. This was reflected in the specific statements of work Boeing issued to its suppliers in connection with its airplane development programs. At the same time, Boeing also began working with its supply chain partners on large-scale system integration efforts. This involved the aggregation of parts and components into discrete commodity groupings and their integration, in turn, into larger subassembly sections of the aircraft. This contributed to a better alignment of how the product is built across Boeing's enterprise value stream, enabling not only an improved utilization of supplier capabilities but also allowing Boeing to put into place a more efficient system integration process, including the adoption of a single-flow production process.

With Boeing taking these two incremental steps forward with its design delegation and large-scale systems work with partners, the company moved towards the process of transforming its product development process, reflecting some key features of the practices Toyota utilizes with its supply chain partners. Although Boeing did not transfer or consolidate the design of any significant parts packages during this period, it was able to transfer, test, and implement design delegation packages with some its most critical suppliers. Concurrently, Boeing's Commercial Division was able to work with its supply chain partners to examine the feasibility of large-scale systems integration, while also learning from its Integrated Defense Systems (IDS) Division. The Boeing Company's IDS Division had been performing Concurrent Engineering and system-of-systems integration on its products for many years, most notably supporting the company's Space related programs.

During this time of corporate learning, Boeing's Commercial Division was able to evolve significant capabilities involving design techniques, which it began to mature and incorporate into a new airplane program concept called the Sonic Cruiser (see Figure 4-4). While marketing the Sonic Cruiser, Boeing began working with its customers, financial institutions, and suppliers to collect insights that could be leveraged into the new aircraft. The overall learning Boeing was able to evolve and consolidate through these interactions would perhaps prove one of the most important during the many decades since its foundation.

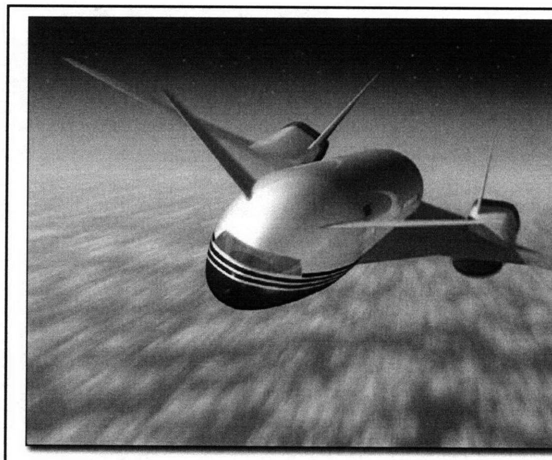


Figure 4-4: Boeing's Sonic Cruiser (Artist Concept)

Source: www.boeing.com

The financial institutions and airline customers that Boeing was working with communicated that they were not currently in the market for an airplane that would fly higher, farther, or faster, which is exactly what the Sonic Cruiser offered the marketplace. Because of the depressed marketplace, the critical stakeholders Boeing was working with communicated that they favored an airplane that would yield lower operating costs more than they would favor gaining a marginal increase in aircraft speed. While the Sonic Cruiser project did not garner the interest Boeing had been seeking from the marketplace, the company did listen intently to the inputs it was receiving. During the third quarter of 2002, Boeing released an artist's rendering (see Figure 4-5) of what the company called the "7E7".

Later that year, Boeing discarded its Sonic Cruiser in favor of the slower but more fuel efficient 7E7. With the knowledge and technology improvements Boeing Commercial Airplanes was able to learn from its IDS Division and supply chain partners during its initial design studies, the company was able to transfer and leverage advancements into the 7E7; thus, all was not lost from the Sonic Cruiser project. Much of the research from the Sonic Cruiser was applied to the 7E7, including carbon fiber reinforced

Figure 4-5: Boeing's 7E7 (Artist Concept)

Source: www.boeing.com

plastic for the fuselage and wings, and no-
bleed engines.

In April 2004, the face of the commercial aerospace industry would forever be changed; Boeing formally transitioned from the concept of the 7E7, launching the 787 Dreamliner with 50 firm orders from All Nippon Airways (ANA) of Japan. The deal was worth about $6 billion at list prices, with deliveries scheduled to begin in 2008. To date, Boeing has sold 802 787 Dreamliners with firm commitments from its airline customers.

4.3 BOEING'S 787 PROGRAM: A PIONEERING EXAMPLE OF PUSHING THE BOUNDARIES OF THE CURRENT-STATE SUPPLY CHAIN ARCHITECTURE AND MANAGEMENT PRACTICE IN THE COMMERCIAL AIRCRAFT INDUSTRY

With the launch of the 787, the Dreamliner, The Boeing Company leaped forward with one of the most significant endeavors in technology advancement, product design, manufacturing application and supply chain management practices the aerospace industry has ever seen. "At its heart, Boeing's 787 is an ambitious project that aims to develop new technology that can save weight and fuel, reinvent various production processes, and offer its airline customers a competitive advantage by emphasizing passenger comfort" (Teresko 2007).

When transitioning into the Dreamliner's product develop processes, the program's leadership team committed to structure itself utilizing matrix alignment between its functionally skilled employees, aligning teams to commodity value streams (i.e., sections of the airplane that, when integrated, would become a whole greater than the sum of its parts, thus creating more value for Boeing its stakeholders). The teams, formally called Lifecycle Product Teams (LCPTs), were shaped with the support of functional resources, including participation from manufacturing, engineering, procurement, and materials management. An additional component of this team structure was the incorporation of an innovative approach that was designed to facilitate collaboration directly with suppliers (see Figure 4-6). The premise of this model was to adopt the concept of forming strategic alliances with equal risk-sharing in the program's initial development cost, design, and subsequent revenue generation. Working with the company's strategic supply chain partners, the LCPTs made a significant design commitment. They were determined that they would make the Dreamliner's airframe out of composite materials, thereby making it the first commercial airplane program with a fuselage made entirely out of composite materials. The decision itself was made as each team met with airline customers and realized the need to make the airplane lighter in weight, so that it would be more economically efficient for the airlines to operate. Once the teams came together, they proceeded forward and collaboratively, determined that moving forward with a composite design would meet the requirements and expectations being driven by the market.

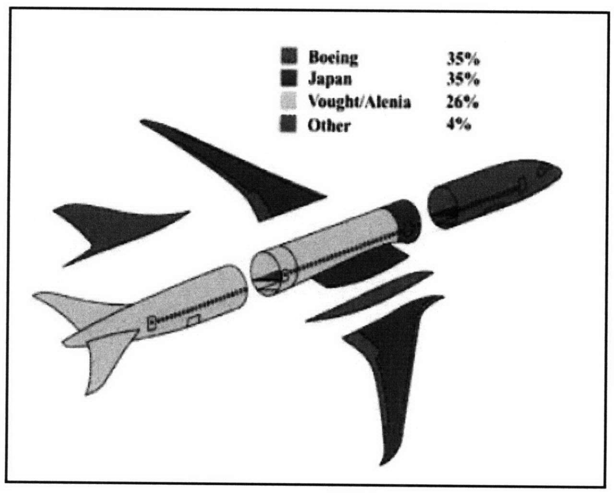


Figure 4-6: 787 Structure Partners/Locations

Source: www.boeing.com

Through the adoption of this aggressive design approach with its partners, Boeing initiated a preemptive strategy (Shapiro and Varian 1999). To date, the strategy has worked extremely well for the company to generate positive feedback in the marketplace, specifically against its primary rival, Airbus. The preemptive strategy Boeing incorporated included the following techniques:

- First to Market and Continuous Innovation – Continuously innovating requires a highly skilled product team with complete mastery of design skills. Speed to market comes from superior design, not by marketing an inferior product. Continuously develop superior product features with significant performance gains on several dimensions including, but not limited to, performance and price. If required, segment product offerings to meet specific needs (low cost, high end features).
- Aggressively build an installed customer base
    - Finding visible, influential customers.
    - Utilized penetrating pricing (price below cost as well as heavy discounting).

Performance expectations were initially major factors for the Dreamliner's customers' buy decisions. Because of this, Boeing worked closely with and actively managed airline customers' expectations. At the same time, Boeing and its supply chain partners had to contend with rival claims that down-played the viability of the composite technology being implemented in the 787 Dreamliner's airframe design. Early into the product development process, Boeing and its supply chain partners knew that the initial product prototypes would need to demonstrate the viability of the composite technology being leveraged into the airplane's design. During the Dreamliner's product development phase, Boeing worked to incorporate the following innovative program management techniques to manage expectations in working with its risk-sharing supply chain partners:

- Assembled allies and built allegiances Boeing kept an open attitude, letting other companies participate in defining and refining technology into the airplane's design.

- Worked with its partners – Boeing worked painstakingly with its supplier partners to address export compliance and regulatory compliance issues, by adopting a common standard – the best system developed by all.
- Psychological positioning – Boeing was very successful in framing its strategy; Airbus formally responded to the 787 with the launch of the redesigned A350-XWB in 2007.

The foundation of this cultural transformation began with Boeing shaping and engraining within itself the concepts and practices associated with establishing a clear-cut vision for the Dreamliner, modeling its organizational structure in a matrix fashion and developing strategic alliances with its development partners. With the complex integration required to develop and produce an airplane program and the added complexity of designing an airframe made out of all composite materials, it might be argued that Boeing and its risk-sharing supply chain partners would perhaps have benefited by adopting an ambidextrous organization structure (see Figure 4-7), an organization in which team efforts are framed “as structurally independent units, each having its own processes, structures, and cultures but integrated into the existing senior management hierarchy” (O’Reilly and Tushman 2004, p. 2).

The power of incorporating this type of team-based structure would have been that the LCPTs organizational interdependencies would have ambidextrously allowed for cross-pollination across teams while eliminating inherent inertia stemming traditional practices.

Alignment of:	Exploitative Business	Exploratory Business
Strategic intent	cost, profit	innovation, growth
Critical tasks	operations, efficiency, incremental innovation	adaptability, new products, breakthrough innovation
Competencies	operational	entrepreneurial
Structure	formal, mechanistic	adaptive, loose
Controls, rewards	margins, productivity	milestones, growth
Culture	efficiency, low risk, quality, customers	risk taking, speed, flexibility, experimentation
Leadership role	authoritative, top down	visionary, involved

Figure 4-7: Scope of an Ambidextrous Organization

Source: O’Reilly III and Tushman 2004

Structuring the company in this fashion would also have enabled Boeing's senior management team to work directly with its internal functional units as well as its supply chain partners, while concurrently enabling business units to share essential resources, such as budget (monetary), intellectual capital, and technology applications. The important point here is that the management team would have been able to serve as important risk mitigation agents to ensure that the supporting LCPTs would not get stuck in "business as usual practices" and would keep their development focus squarely on the top-level vision associated with the Dreamliner.

As incorporated in the Dreamliner's design process, Design for Manufacturability (DFM) a disciplined process for designing high quality, cost-effective products intended to meet the company's airline customers' requirements and expectations. DFM relied on heavy participation from the Dreamliner's LCPTs and state-of-the-art design technology and analytical techniques. Coupled with partners participating in the design process, DFM was unique because it emphasized extensive problem formulation and resolution, and establishment of product concepts prior to developing formal engineering drawings. DFM provided the 787 Dreamliner's development teams with methods for generating multiple concepts and analytical tools for identifying the best solution for the airplane's design. DFM also addressed detail design issues and identified testing requirements, ensuring that customer design expectations would be totally met. The importance of this cannot be understated, especially with strategic supply chain partners participating directly in the Dreamliner's design.

Working collaboratively with its strategic risk sharing partners, Boeing leveraged multiple viewpoints and the available intellectual capital to formulate the airplane's conceptual design to develop a physical product. During this phase, the LCPTs gathered information required to develop a world-class airplane. Problem formulation was the most time consuming phase the LCPTs encountered during the Dreamliner's development process and the success of the end product design was 100% dependent upon the quality of research and analysis performed during this phase of the airplane's product development process. Problem formulation ensured that all restrictions, boundaries, and requirements for the airplane's design were identified and integrated between the programs LCPTs.

The 787 Dreamliner's DFM processes, for the most part, relied on traditional Concurrent Engineering efforts that typically include representatives from disciplines and companies that come into contact with the product's design during its development cycle, from requirement definition to physical build-up and integration of the aircraft.

- An important benefit Boeing derived working with its risk-sharing supply chain partners is that the company was able to work directly with its partners to benchmark and incorporate industry best practices. In doing so, Boeing was able to develop new design features. Also achieved were additional benefits. As a result, Boeing: Assessed how the product measured against sustaining designs in the marketplace;
- Identified alternative design solutions that could be leveraged; and,
- Fostered product concepts to leapfrog existing products in the marketplace.

Ultimately, working in the LCPT matrix organizational structure allowed the cross-functional teams supporting the program to work together to design the Dreamliner for assembly. During this phase of the development process the LCPTs worked together to optimize the airplane's design so that system integration would go smoothly and very quickly during the Dreamliner's final assembly processes.

Achieving robust design in the program required an understanding of the variation in the Dreamliner's various requirements and manufacturing processes to maximize the performance of individual components and subsystems that would be integrated into the airplane. Robustness of the Dreamliner's design was influenced throughout the airplane's product development process. Three common challenges the LCPTs faced during the design process were sources of variation caused by the customers, process capability, and customer "use and abuse" of the built aircraft.

An additional, and welcome, benefit that was realized during the Dreamliner's initial design phase was the surface strength of airplane's composite airframe. Unlike Boeing's sustaining (on-going) airplane programs currently in production, which are made of polished aluminum skins and stringers, the Dreamliner's airframe proved to be very strong and resistant to damage traditionally incurred during aluminum manufacturing build processes. The realized benefit should prove beneficial to the airplane's in-service maintenance in the future, which will provide Boeing's airline customers significant cost avoidance opportunities by saving costs associated with performing routine aluminum repairs when the airplane enters into service.

Manufacturing processes performed during the build of an airplane necessitate specific tolerance requirements that must be upheld by having in place the requisite manufacturing capabilities. With new technology being infused into the Dreamliner's design, the technology changeover initially posed a challenge to the LCPTs; yet, the integrity of the airplane's design and performance characteristics remained the top priority the company and its supply chain partners. Understanding the airplane's initial product development gaps, and designing the product with knowledge gained through the DFM process and preproduction simulation steps the LCPTs had taken, proved to be extremely important factors in designing and developing parts that were more efficient to manufacture and easier to install, and which are expected to be more robust through the airplane's in-service lifecycle. For instance, Mike Bair, Boeing's former leader of the program and one of its biggest advocates points out, "by not being susceptible to fatigue and corrosion, composites will enable the airlines to stretch intervals between "heavy checks" to double the six- year interval specified for aluminum" (Teresko 2007). Understanding these process capabilities also minimized variation in the enabling the reuse of parts design as the program evolved sometimes with only minor design changes at the detail parts level, which proved important in reaching important design and performance goals and metrics, especially those pertaining to the airplane's weight.

The third benefit yielded through the Dreamliner's robust product development design process was information gained through customer "use and abuse" of airplanes already in service. A detailed understanding of how a customer "uses and abuses" an airplane allowed the team to develop a product that will satisfy the required service-life customers are expecting, which is estimated to be around 40 years for the 787 Dreamliner.

In addition to DFM, rapid prototyping and physical mock-up simulations were used for quick validation of the Dreamliner's design concepts. Supply chain partners working collaboratively within Boeing's LCPTs were able to quickly build up concepts, including foam-core, plaster or paris, and stereo-lithography, in the process modifying production parts and other gross mock-ups of space and movement that were included in the airplane's design. This type of prototyping provided concise assembly of 3-D parts, such that design and production concepts pertaining to the airplane's new technology features could be readily communicated and tested. This allowed the identification of opportunities as they arose, so that design enhancements could be leveraged and incorporated into the airplane's baseline design.

Once the prototyping efforts were completed, the detailed design phase of the airplane began. The detail design phase included final manufacturing process selection and analysis to ensure the robustness of the product. The work performed by the LCPTs included intense tolerance analysis, Boeing Quality Management System (BQMS) analysis, hardware variability control measuring, understanding of manufacturing process capabilities, and computer modeling, such as Digital Pre-Assembly (DPA) and Finite Element Modeling (FEM). More refined prototype hardware was then utilized in the Dreamliner's detail design phase to verify performance of the product.

A large part of the LCPTs' ability to validate design of the airplane included resolving risks by prototyping and performing continuous improvement techniques, testing to verify service-life, ensuring form, fit and function, completing qualification and certification testing, and completing analysis which documented the Dreamliner's performance. It was extremely important for the teams to work together to answer all the questions that arose during this aspect of the airplane's design cycle. In addition, testing served as a means of ensuring product robustness in all areas of customer use and abuse. This step was taken to avoid or minimize any negative performance-related incidents that might be observed following the airplane's introduction into service, ensuring that a service-ready product will be delivered to customer airlines without any heartburn.

As outlined above, the complexity, technology, and innovation required to produce an airplane like the 787 Dreamliner does not stand alone. Two extreme notions are introduced to frame the ensuing discussion: great products and network effects. For great products, airline customers base their purchase decisions on the intrinsic value of the product to them. In other words, what would this be worth to me if I were the only buyer in the world? Unlike great products, network effects expose a completely different market dynamic. Airline customers base purchase decisions on the size, actual or projected, of the installed base and/or the future availability, actual or projected, of complementary products and services. In other words, how many other airlines would be likely to buy the 787 Dreamliner? In this case, the scenario ties-back heavily to the 787 Dreamliner's customer-base in the global marketplace.

Aerospace sales compete in a highly technical market dominated by a "winner-take all" mentality and competitive landscape. In addition, the commercial airplane industry has several market segments and products that overlap (see Figure 4-8).

In light of this market reality, the development of the Dreamliner marked a new trend to dominate multiple markets. The "winner-take-all" market condition has been and will continue to be influenced by the following factors:

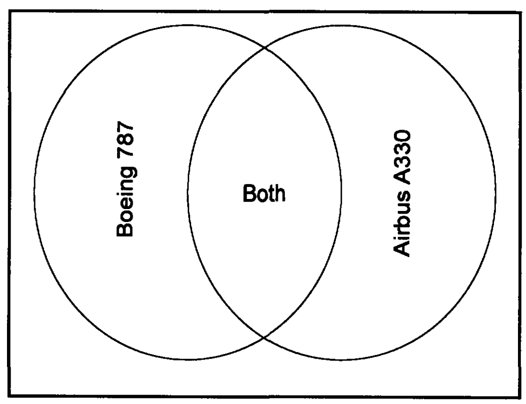


Figure 4-8: Market Relevance – There is market overlap creating an opportunity for one solution

- **Economies of Scale**: the size of the market is large, giving one technology a sustainable cost advantage – composite airplane vs. traditional aluminum airplane.

- **Switching Costs**: Once customers invest in learning how to use the dominant technology embodied in the airplane, there are switching costs involved in adopting a different technology; this is demonstrated through the use of composite technology, as well as through the 787 Dreamliner's highly innovative interior design.
- **Direct Network Effects**: product value increases with the size of the customer and service route network that is already created, due to direct links.
- **Indirect Network Effects**: product value increases due to the number of complementary products and services available (i.e., internet connection availability and in-flight entertainment packages).

Innovating new technology improvements in the aerospace marketplace depends on the emergence of both types of network effects, direct and indirect. When the network effects are strong, market share itself creates value. Network effects "arise when one market participant affects the other without compensation being paid" (Shapiro and Varian 1999, p. 183). Effects can be both positive and negative. Positive network effects provide positive feedback. When a customer buys the technology, the value of the technology is enhanced by the strength of the network; "[t]he value of creating and connecting the network depends on the number of other customers already connected to it" (Shapiro and Varian 1999, p. 183). Given rival products of approximate equal cost, buyers choose the product that was already chosen or the one that appears likely to be chosen by the greatest number of users, which has been reflected in the success of selling the 787 Dreamliner. The company has sold to the capacity of its order-base through roughly 2015.

Building complementary assets is potentially a three-fold process: build assets with your own resources, build assets with alliances, or both. For Boeing, the approach included delivering the initial product offering and educating the market about the Dreamliner's technology changes so that the airplane's potential customer-base felt comfortable with the product. The critical focus was on building strategic alliances with risk-sharing supply chain partners to develop complementary assets that would contribute to the creation of an airplane program that would appeal to the airline customers and stimulate real customer demand. Building alliances proved difficult with the Dreamliner. It did and will continually require the ability to find willing partners, fostering market innovation and technology development relationships. Knowing how to get the bandwagon rolling was every bit as important for the Dreamliner as the incorporation of strong product development design skills. Through the creation of risk-sharing supply chain partnerships, each participating company made investments to ensure the success of the airplane's development. As such, the 787 Dreamliner was made better through the efforts of Boeing's coalition of partners, converging together to help develop and design the product. Through the formation of these alliances, the participating companies were able to reinforce the creation of a positive feedback-looped process of mutual learning and improvement. By creating the necessary complementary assets through joint development and marketing efforts, Boeing and its supply chain partners have responded to the needs of the airline customers, with the expectation that this would translate into dominance in the global marketplace.

The net result of building network effects, both indirect and direct, was focused around the strategy to "tip" the "winner-take-all market" in favor of The Boeing Company and its risk-sharing supply chain partners. Market tipping in the aerospace market, when it occurs, is a very powerful force, locking-in airline customers who might otherwise have chosen less desirable airplane platforms available in the marketplace.

In this portion of this thesis, I have attempted to outline the quintessential understanding Boeing has gained through the 787 Dreamliner pertaining to where the company strategically wants to take its business. It is my belief that when The Boeing Company's Board of Directors authorized the launch of the 787 Dreamliner and decided to take a holistic approach considering variables, such as: (1) vision with a preemptive strategy; (2) organizational structure leading to cultural change - utilizing complementary assets to carve market niches and create systemic network effects among airline customers; and (3) the forethought to create strategic risk-sharing supply chain partnerships to leverage market position. In doing so, the company yielded tremendous success and was able to recapture market share in the lucrative commercial airplane twin aisle sector with stellar sales in 2005, 2006, and 2007.

Does the product matter? Does the innovation process matter? Absolutely! When Boeing entered the market and introduced an operating framework that was robust and diverse enough to offset convergent market forces, it achieved tremendous success. As the company carries these advances over to future launch platforms it should expect continued success and should find its way back to long-term market dominance. In other words, The Boeing Company's new innovative enterprise architecture framework is robust and its very existence has quickly become the company's specialized complementary asset, defining its dynamic organizational capability. In spirit, the company's operating framework that has been leveraged with the development of the 787 Dreamliner has, in fact, become its unseen competitive differentiator that will resonate with its airline customers and will quite likely shape the mindset of its primary competitor. The challenge for The Boeing Company will be to move with agility and ensure that, as it matures its new and innovative enterprise architectural framework, it will remain both robust and agile to keep the company in front of the market's learning curve. This will enable Boeing to make itself the new global benchmark in aerospace, with complete brand recognition in the marketplace.

Moreover, even though the 787 has experienced an initial delivery delay and will most likely not deliver its first airplane to ANA until the end of 2008, the organizational model itself has proved advantageous. While the project is taking more time than originally anticipated, "Boeing remains confident in the design of the 787, and in the fundamental innovation and technologies that underpin it."[13] These innovations and technology advancements would not have been feasible without Boeing taking the revolutionary and pioneering collaborative approach in developing, procuring, and producing the Dreamliner with its risk-sharing supply chain partners. This is why the Dreamliner is, and forever will be, a "game changer" in the commercial aerospace industry.

4.4 Scalability of Toyota's Supply Chain Management Practices within Aerospace

While this thesis has focused dedicated sections to a review and analysis of the Toyota Production System in order to assess its applicability to the aerospace industry, the main question posed earlier has not yet been addressed: would it be possible for the commercial aerospace industry in general, and for Airbus and/or Boeing in particular, to fully adopt the principles and practices characterizing the Toyota Production System (TPS) to transform and optimize current aerospace supply chain management practices? As it has been stressed earlier, the TPS is much more than just "tools" used to implement incremental

[13] Jim McNerney, when announcing the six-month delay of the 787 Dreamliner.

process improvements. The TPS is, in fact, a holistic approach to system-of-systems management, focused on the cultivation and improvement of the entire production system's performance. "System of systems being a moniker for the collection of task oriented or dedicated systems that pool their resources and capabilities together to obtain a new, more complex, 'system' which offers increased functionality and performance than simply the sum of the constituent systems."[14] In addition, the TPS has gone through multiple decades of cultivated growth and transitions with the company's most recent release of the Toyota precepts presented to the public in 1997.

To the question on the table concerning whether it is possible for one or both of the two major aerospace OEMs to adopt the TPS, the answer is an emphatic "yes", with one important caveat. Either Boeing or Airbus could adopt the TPS, by leveraging primarily the following elements:

- Precepts and management principles;
- Supply chain architecture;
- Product development practices; and,
- Procurement methods.

The important caveat is that if one of the OEMs were to fully adopt the holistic system-of-systems approach Toyota has incorporated with the TPS, the adopting company's leadership and its major stakeholders, including its employees, must craft an integrated transformation process spelling out the enterprise "system" boundaries, the enterprise's strategic and tactical focus, management principles and practices, and the role

[14] www.wikipedia.com

of the employees. As demonstrated throughout this thesis, Toyota has been evolving and continuously refining its system-of-systems approach with the TPS over a long period of time, by building on basic precepts even well before the years of Eiji Toyoda and Taiichi Ohno. The fact is that the founding precepts the TPS was founded upon date back to Sakichi Toyoda, while he was building-up Toyota Automatic Loom Works. Perhaps the greatest learning I have gained while writing this thesis is that Toyota has been able to organically grow and evolve the basic tenets and supporting principles and practices from the roots-up, where the core of the system is based on the premise of the learning organization.

Adopting a learning organization approach has enabled Toyota to test its principles and practices constantly in order to improve them. It has also involved the utilization of processes, where employees are always encouraged to observe, identify and recommend improvements associated with the work they perform, thus giving them a sense of ownership in the enterprise system. Consequently, the TPS has been embedded in the Toyota Motor Corporation's corporate DNA. If one of the two major commercial aerospace OEMs were to adopt the TPS without paying attention to these basic points and instead by simply employing some of the TPS "routines" or tools, they would surely fail. Therefore, if one of the OEMs were to fully adopt the TPS, it could borrow Toyota's framework and well known tools, but would need to understand that fully adopting the TPS would mean committing to a long-term, strategically focused, organic approach to strategically, tactically and operationally transform its existing supply chain management methodologies and management practices by incorporating a holistic system-of-systems approach to optimize its supply chain business performance. At the same time, the adopting OEM would need to ensure its model adaptation of the TPS included robust process design that would transform existing arms-length supplier performance, building up collaborative relationships between risk-sharing partners based on the foundation of trust.

In the next section of this paper, we will examine a future-state roadmap the OEMs could leverage to adopt the TPS into their supply chain management methods and practices. In addition, we will examine strategic elements, foundational design considerations, and implementation tactics that the aerospace OEMs would need to leverage to successfully leverage the TPS in order to transform their supply chain management principles, practices, and methods.

5 DESIGNING THE FUTURE-STATE AEROSPACE SUPPLY CHAIN ARCHITECTURE

The transformation process associated with transitioning current-state supply chain management design methodologies prevalent throughout the commercial aerospace industry to craft a future-state design would be a massive undertaking for either Boeing or Airbus to take-on, especially during a period when product sales are peaking and the industry as a whole is near its capacity limits. In order to shape the future-state architecture, leveraging the framework and tools utilized by Toyota and embodied in the TPS, the OEMs would need to take a long-term, dedicated approach in order to achieve the transformation process. While such a transformation process would by no means be an easy one, it is nevertheless feasible and within grasp. It is important to underscore the point, once again, that Toyota provides important lessons in the way it has pursued its globalization strategy, developed its North American operations, and has progressively and methodically evolved a learning organization that has successfully cultivated and developed its supplier networks. Just as Toyota did throughout North America, Airbus and Boeing could incrementally transform and align their global supply chain networks within the framework and context of the TPS.

The remainder of this thesis will utilize the Supplier Networks Transformation Toolset developed by the Supplier Networks Working Group of the Lean Advancement Initiative (LAI), formerly the Lean Aerospace Initiative (LAI), at MIT. This Toolset, developed under the leadership of Dr. Bozdogan at MIT and issued in 2004, encompasses two integrated tools. The first, the *Roadmap for Building Lean Supplier Networks,* provides a structured process that any OEM or major supplier can use to design and build lean supplier networks by transforming its current-state supplier management architecture, utilizing lean thinking principles, six sigma practices, and associated initiatives for continuous process improvement. The second, the *Supplier Management Self-Assessment Tool (SMSAT)*, is a user-friendly tool companies can use to gauge their degree of progress in developing lean supply chain management capabilities, using a capability maturity model embodying lean supply chain management principles as well enabling practices arrayed and described in the form of five distinct levels of capability attainment. The discussion below will strive to demonstrate how one of the two OEMs could use this Toolset to define its current-state supply chain management architecture and then proceed to design and build its desired future-state supply chain management architecture, reflecting the adoption of fundamental TPS principles and subsequent research-based lean enterprise principles developed at MIT under the auspices of LAI. The Toolset can be accessed through http://lean.mit.edu/.

5.1 Future-State Aerospace Supply Chain Management Roadmap

While many tools exist in the public domain that could be leveraged to support the strategic transformation of the commercial aerospace industry's supply chain management network, principles, and methodologies, I will use the *Roadmap for Building Lean Supplier Networks* to outline a recommended future-state transformation process. The roadmap outlines the following key building-block considerations to transform the current system (*Roadmap for Building Lean Supplier Networks* 2004, p. 5):

1. Define vision
2. Develop supplier network strategic plan
3. Establish lean culture and infrastructure

4. Create and refine lean implementation plan
5. Implement lean initiatives
6. Strive for continuous improvement

While the roadmap will be summarized in a linear outline, the framework itself is a closed-feedback-looped model with slow-clockspeed and fast-clockspeed spheres of improvement that are closely linked together as they are implemented over time. In this context, the importance of working from the OEM's own production line, observing and learning opportunities for the future-state design of the system, cannot be overstated. The discussion below will only summarize the key roadmap elements, not the specific implementation steps associated with tool that are described in great detail.

1. Define Vision

As with any strategic and tactical project implementation effort, first defining the future-state vision that is sought is absolutely critical. At this stage, the OEMs would need to clearly define the precepts guiding their transformational efforts. The gap between the current-state supply chain management architecture and the desired future-state definition derived from the articulation of the future-state vision will serve as a powerful motivator for embarking upon the transformation journey. With this in mind, the OEM would be setting the guiding precepts, management principles, and methodologies that would guide the company's future business model, rules, roles and responsibilities, and relationships throughout the end-to-end supplier network. Inherent to the Vision Definition phase would be the importance of the OEM working with its supply chain partners to build a sense of alignment, collaboration, and trust, where trust-based relationships become infused with demonstrated, closed-loop, follow-through actions. The *Roadmap for Building Lean Supplier Networks* highlights the following important aspects pertaining to vision definition:

> The vision of the supplier network represents a direct extension of the corporate vision, goals, and objectives. The size, structure and composition of the supplier network are governed by the enterprise's defined vision and business model. They drive enterprise-wide strategic initiatives, which must be shared throughout the supplier network. The vision statement and the business model reflect the enterprise's view of its portfolio of core competencies and how it proposes to align core competencies through the supplier value stream. Ultimately, the enterprise's supplier vision represents, in itself, a central core competence to enhance the enterprise's competitive advantage (*Roadmap for Building Lean Supplier Networks* 2004, p. 8).

For this reason the vision can be leveraged to establish a strategic and tactical focus aligned with implementing the supply chain transformation effort. As used in Toyota, through the annual hoshin planning process, the precepts could provide a context, at the highest-level, for the transformation efforts taking place within the supply chain network. Moreover, if communicated and arranged properly with strategic networks of suppliers, the precepts could be utilized to guide supplier associations, through them, to lower-tier suppliers as well as to sub-tier suppliers that are often invisible to the OEM. Important considerations to take into account during the vision definition phase include (*Roadmap for Building Lean Supplier Networks* 2004, p. 8):

- Does the OEM have an explicitly defined enterprise vision and business model to guide its supply chain design, management strategies, and activities?
- Is top leadership committed to the adoption of the lean principles?
- Does the OEM have a well defined, robust value proposition with key suppliers spelling out mutual expectations concerning value exchanges? Is the value proposition differentiated for different categories of suppliers?

- How does the OEM evaluate the degree of integration between its supply chain design and management activities across its enterprise and its enterprise-wide lean transformation initiatives
- Where is the OEM's enterprise on its lean journey? Does the OEM have hard evidence supporting its conclusions?

Working through these questions and coming up with a concise, strategically and tactically focused vision and a set of core precepts supporting it, will enable the OEM to begin working its strategic plan to engage with its supplier network.

2. Develop Supplier Network Strategic Plan

Because of the size and scale of part variation produced in the commercial aerospace industry, the importance of developing strategic supplier network plans would be critical to support the transformation process. To optimize the effort's focus, rather than taking a traditional commodity approach to align its supplier network plan, I would recommend that the network be aligned by value stream associations that feed the build of an airplane. Recalling again my observations given earlier pertaining to Toyota's Georgetown facility, the installation processes they were supporting within the production line to install engines would not have been possible through a commodity focused plan. To achieve the level of optimization Toyota demonstrated, various types of waste had to be taken out of the value stream. Without optimizing the efforts concentrating on value stream flow, disconnects could arise that could sub-optimize the entire effort; commodity focused plans only optimize the single commodity and therefore could potentially handicap other elements of the plan.

The *Roadmap for Building Lean Supplier Networks* highlights the following important aspects pertaining to developing a supplier network strategic plan (*Roadmap for Building Lean Supplier Networks* 2004, p. 8):

> The strategic plan should identify the current-state of the supplier network, define a desired-state, and provide a recommended course of action to achieve the development of a lean supplier network. It should identify the improvement opportunities, barriers, and costs and benefits associated with the implementation of the strategic plan. The plan should identify a single point of contact for its achievement and the individual(s) with the organizational responsibility and resources to accomplish the specific elements of the plan within budgetary constraints.

Therefore, the strategic supplier network plan must implicitly outline the steps that need to be taken to tactically transform the supply chain system, incrementally transitioning form the current to future-state. Important considerations to contemplate during the supplier network planning phase include (*Roadmap for Building Lean Supplier Networks* p.9):

- Does the OEM have a structured process for linking its enterprise vision and business model to its supplier network design and management activities?
- Does the OEM have a working familiarity with strategic lean concepts and practices governing lean supply chain design, development and management?
- Does the OEM know the *current-state* of its internal lean supply chain management capabilities?
- Does the OEM have a clear understanding of the *desired future-state* of its supplier network?
- In defining the *desired future-state*, has the OEM considered its enterprise strategic make-buy criteria, key value-creating processes across the enterprise value stream and the enterprise's future need in terms of required core competencies, and how best to optimize these core competencies across the supplier network?

Through the planning process, the incorporation of the learning organization philosophy is a very important element to instill. Through the incorporation of the learning organization platform, the OEM could work with its specific value-stream-aligned supplier networks. Also, through a process observation, learning, and experimentation, the OEM can explore and define answers that would help shape improvement opportunities that might otherwise be overlooked. Therefore, the plans worked with the supplier networks need to have elasticity in their deliverable definitions, and understanding the future-state, keeping in mind that achieving optimal performance in the future is always a moving target.

As part of the Strategic Planning block of implementation steps, the Roadmap Tool invites the user company to perform a self-assessment of lean supply chain management capabilities, to define the current-state as well as the desired future-state and identify the gap for improvement actions before proceeding further in implementing the Roadmap. Such a self-assessment is performed by using the Supplier Management Self-Assessment Tool. This tool defines eight overarching lean supply chain management principles and the more detailed enabling practices supporting each one of these eight principles. These eight overarching principles are summarized below (see Table 5.1, next page).

1.0 Design supplier network architecture – Design the size, structure and composition of the supplier network to ensure efficient creation of value for all stakeholders.
2.0 Develop complementary supplier capabilities -- Develop complementary supplier capabilities to enhance the portfolio of core competencies in the extended enterprise.
3.0 Create flow and pull throughout the supplier network -- Create synchronized flow throughout the supplier network to evolve a "pull"-based production system that ensures continuous flow maximizing the advantage of speed
4.0 Establish cooperative relationships and effective coordination mechanisms -- Develop a differentiated set of relationships with suppliers including supplier partnerships and strategic alliances, while balancing cooperation and competition, to optimize network-wide performance.
5.0 Maximize flexibility and responsiveness -- Integrate processes, practices and information flows across the supplier network to maximize network-wide flexibility, adaptability and responsiveness to cope effectively with sudden external developments.
6.0 Pursue supplier-integrated product and process development – Integrate suppliers early into the design process to ensure delivery of best lifecycle value.
7.0 Integrate knowledge and foster innovation – Create knowledge-sharing processes and foster innovation across the supplier network to ensure continuous flow of innovative solutions benefiting the customer and other enterprise stakeholders.
8.0 Demonstrate continuous performance improvement – Institutionalize formal processes and reward systems for continuous improvement throughout the supplier network to deliver best value to all stakeholders on an on-going basis.

Table 5.1: Eight Supply Chain Management Principles

Bozdogan (2008)

3. Establish Lean Culture and Infrastructure

This is the most important step included in the roadmap process. At the heart of this thesis is the importance of creating a culture based on importance of observing, "going to see", utilizing the learning organization, testing, and cultivating the culture based on the philosophy of relentlessly eliminating waste from the system. Moreover, the culture needs to stimulate individual, company, geographic, and environmental improvement. The goal is not only to improve the single system element being worked but the larger system encompassing the entire enterprise, by taking a holistic approach. Key considerations the OEM would need to consider to successfully transform its lean culture and infrastructure include (*Roadmap for Building Lean Supplier Networks* 2004, p. 9):

- Is the OEM committed to making the necessary investments in terms of infrastructure, training and education to develop the necessary lean supply chain management culture, structures, and tools?
- Has the OEM aligned critical processes and procedures across its enterprise, creating standard work and tools that bridge into the company's supply chain network?
- Is the OEM's enterprise fully Internet capable, with Internet speed? Has the company ensured that lower-tier suppliers, as well, are linked electronically to key suppliers to ensure visibility and responsiveness throughout the supplier network?
- Does the OEM have the right incentives and reward systems both internally and across its supplier network to make sure that the entire network, operates as efficiently and effectively as possible so that the enterprise can create and deliver value to its stakeholders?

These indeed represent very important considerations; essentially, the elements outline thoughts pertaining to how robust the system needs to be to achieve the types of performance achieved in the TPS, challenging how serious the OEM is, not only in terms of making the needed monetary investments but also the necessary intellectual commitments and relationship-specific to build a collaborative supply chain network that is based on solid precepts reflecting the premise of the learning organization.

4. **Create and Refine Lean Implementation Plan**

As discussed earlier in this section, the importance of incorporating a flexible plan with deliverables that can be adjusted annually is critical to the process of transforming the supply chain network. While the overall precepts may not change during the course of decades, as well demonstrated by Toyota itself, the specific elements supporting them should be constantly scrutinized and challenged in order to continuously perform better through the learning organization approach.

> This block of activities entails the creation and refinement of lean implementation activities. Necessary steps include supplier value stream mapping and analysis, the identification and prioritization of lean implementation initiatives to bridge the "gap" between the "current state" and the desired "future state", the deployment-ready development of implementation tools and methods as well as the provision of the needed training programs, and the commitment of resources for implementation. Here, suppliers are segmented into categories based on strategic criteria, and differentiated supply chain management approaches are defined to minimize transaction costs and maximizing value creation. Where appropriate, joint lean deployment plans are developed with key suppliers. Information is shared with suppliers regarding costs, risks, and potential gains, as well as how to incentivize them to continuously drive down cost while enhancing value delivered to the end-user or customer. Strategic supplier relationships and alliances are defined. Concrete procurement plans are developed, including Internet-enabled procurement of parts and materials. The lean toolset is developed and/or assembled to meet the needs of the next block of actual implementation of lean initiatives (*Roadmap for Building Lean Supplier Networks* 2004, p. 10).

Through the annual planning and refinement process, with demonstrated commitment and incremental building of trust, the OEM should be proactively engaged with its supplier network in diffusing TPS concepts and practices throughout its extended enterprise, thus infusing a TPS-like system into its DNA. In creating a TPS-like system by using the framework and tools of the TPS, the OEM would need to step up and demonstrate ownership of its guiding values, precepts, and workflow practices extending throughout its supplier network. As with previous building blocks of the roadmap, important aspects the OEM would need to consider to successfully create and refine its lean implementation plan includes the following considerations (*Roadmap for Building Lean Supplier Networks* 2004, pp. 10-11):

- Has the OEM established structured processes internally to evolve integrated improvement action plans in cooperation with the product development, manufacturing, quality improvement and other major process and process owners across the enterprise?
- Does the tactical implementation plan consider all of the overarching and enabling practices outlined in a self-assessment tool and how these practices would shape the OEM's specific processes, functions and activities across the enterprise?
- Has the OEM developed a system of metrics for developing its internal supply chain management capabilities as well as for evolving a lean supplier network?
- Does the OEM and its partners leverage flow mapping?
- Has the OEM given explicit attention to the development of the required educational and training materials and initiatives?
- Are the appropriate tools in place to support implementation?

Once the supporting infrastructure, standard processes and tools are in place, have been tested, simulated, and refined, implementing the system-of-systems approach across the supply chain network becomes the principal focus of the transformation effort. Annually, unless significant process defect exist, the infrastructure, standard processes and tools should be updated through insights gained from the actual process improvement implementation activities. Utilizing this approach will minimize configuration control constraints and will also provide opportunities for the supplier network, similar to BAMA, to provide inputs to the OEM to pursue process improvement opportunities designed to eliminate waste throughout the system.

5. Implement Lean Initiatives

Implementation of the identified implementation steps represents a continuous improvement process. At all times, implementation efforts should focus on accomplishing the transformation process. Intrinsically, the guiding principles holding the implementation efforts together should reinforce the enterprise's basic tenets fostering and nurturing the values of the learning organization. The supplier network roadmap highlights (*Roadmap for Building Lean Supplier Networks* 2004, p. 12):

> The implementation activities span all actions across the extended enterprise (i.e., both internally and across the supplier network) aimed at developing the required capabilities and integrating the supplier network in order to achieve the enterprise-level vision and strategic objectives, supported by the lean infrastructure system. The implementation of the plan embraces the coordination, synchronization and integration of all engineering, manufacturing and assembly, subcontracting, procurement, material, and quality functions, and further includes off-site manufacturing support, contract manufacturing, third-party logistics and customer support functions...
>
> In implementing lean initiatives internally within the enterprise, senior managers and executives must be both committed and must lead. They must help remove barriers and facilitate the deployment of enablers. They must ensure the participation of all people who can make a contribution to the needed change process. Communication is critical in this process. It is important to identify, demonstrate and reinforce results visibility throughout the organization. Rewards should be provided to recognize both individual and team performance towards achieving the established metrics. Conflicts between "old" and "new" ways of doing business must be manager. Constancy of intent and purpose must be communicated widely and consistently to discourage skepticism and to fend off uncooperative behavior reflecting the misplaced feeling that the transformation process yet another "flavor-of-the-month" initiative.

Throughout the transformation effort, the utilization of Deming's Plan – Do – Check – Act (PDCA) processes are pertinent to support implementation efforts within the OEM and its supply chain network. In addition, a critical element the OEM's top leader will need to determine is where the OEM will implement its efforts and with whom. Because of the size, scale, and complexity of the aerospace supply chain, it may not be possible to support the efforts of all suppliers in the course of the transformation process, since there just are not enough available resources to support an implementation effort of this massive magnitude. A determining factor the OEM would need to consider early in its strategic planning process would need to be who the company's key risk-sharing supply chain partners would be, also considering with whom the OEM would need to form new relationships in light of key technological developments in the industry. While the closely-knit relationships indicated in this discussion suggest the adoption of an organic extended enterprise perspective, it is also necessary to keep in mind the necessity to attain and retain flexibility. The door needs to be kept open to benefit of new technological advances, by monitoring early technology adopters who may then be added to the OEM's supplier network. Pertaining to implementation, important aspects the OEM would need to consider to successfully create and refine its lean implementation plan include (*Roadmap for Building Lean Supplier Networks* p.12):

- Has the OEM identified a comprehensive set of prioritized initiatives driven by the overarching (and related enabling) practices governing lean supply chain management? Are these initiatives fully integrated with the priorities of the product development, manufacturing, and other groups within the enterprise.
- Have lean implementation team been established, with governing timelines, milestones, outcome measures.
- Is there a shared destiny between different implementation teams? Have implementation efforts been clearly communicated to the supply chain network and are implementation dependencies between lower and higher tier supplier understood?
- Has the OEM anticipated the various barriers lean implementation efforts initiatives?

The implementation process will incrementally begin the system's transformation process. During implementation efforts and at the end of each year, it is vital for leadership to engage and focus on tactics that will continue the evolution of the transformation process. During these periods of reflection and assessment, earlier expectations need to be reconsidered and perhaps recalibrated, for instance to retain process stability and cohesion within the system. Utilizing clear expectations and forming an understanding about what is normal in the system will help focus and clarify performance objectives and employee roles, helping to expel non-value-added activities taking place in the system. Almost always, employee intent is quite likely well intended; however, sometimes good intentions sometimes do not necessarily align with the company's strategy and tactical focus. Lastly, implementation efforts should be used as fertile laboratories for defining new worker training and skill-development requirements.

6. Strive for Continuous Improvement

In the words of Taiichi Ohno, "The Toyota production system, however, is not just a production system; I am confident it will reveal its strength as a management system adapted to today's era of global markets and high-level computerized information systems"(Ohno 1988, p. xv). These very simple words Mr. Ohno included in the preface to the English version of his book, *Toyota Production System – Beyond Large-Scale Production* are probably words that, quite likely, many readers of his book simply skipped through so that they could read about the TPS. However, Mr. Ohno's words are fundamentally correct, as the system's major architect. Mr. Ohno knew that the foundation of the Toyota Production System resides in the spirit of the system, in its precepts, and in its learning organization approach, while undoubtedly the tools and methods associated with the TPS are important enablers. Fundamentally, the TPS strives to instill a learning organizational culture where employees and partners to work together to relentlessly optimize the system through the elimination of waste via continuous improvement.

Factors to be considered while striving for continuous improvement include (*Roadmap for Building Lean Supplier Networks* 2004, pp.12-13):

- Does the OEM have a structured process in place for evaluating results against future-state goals and metrics on an on-going basis?
- Does this structured process enable the OEM to identify opportunities for continuous improvement across the extended enterprise (the OEM's plus the entire supplier network)?
- Does the OEM have in place a proactive process for nurturing continuous improvement throughout the extended enterprise?
- Will the OEM communicate needed changes with its enterprise vision, strategy and support infrastructure based on its continuous improvement activities
- Can the OEM capture, adopt and rapidly communicate new knowledge gained through its continuous improvement activities throughout its supplier network?

Through these steps, and by understanding the eloquent wisdom provided by Mr. Ohno, the OEM can begin to comprehend the totality of the enterprise as a system beyond production operations and can thus embrace the notion of the learning organization as the basic organizing framework to drive out waste and optimize the performance of the entire system. In the "winner-take-all" commercial aerospace industry the roadmap tool described above could be an extremely useful method for achieving significant competitive advantage and long-term dominance in the marketplace.

6 Conclusion

To shape the aerospace industry's future-state supply chain management practices by leveraging the framework and tools utilized by Toyota as they are embodied in the TPS, the OEMs will need to take a long-term, dedicated approach to the task of transforming their enterprises. While the transformation process will not be easy by any means, it is nevertheless both necessary and feasible. An important lesson I have learned during the more than ten years as I have been actively involved professionally in implementing lean methods and practices throughout the aerospace industry is that the production process will always, unfailingly, expose system disconnects, defects, and supporting functional process wastes (i.e., engineering, manufacturing, procurement, materials management, supplier performance). Hence, going to the production floor, *gemba*, to observe, identify, learn, and test what needs to be worked to eliminate root-cause of waste in the system is of paramount importance to the overall transformation process.

Considering the scale and magnitude of a transformational undertaking involving an entity as large as the aerospace supply chain suggests that adopting the TPS principles and methods by Airbus and/or Boeing would require that a robust process design must be put in place and standard products and services must be incorporated as fundamental early steps in the implementation process. At the same time, without having the supporting precepts, management principles, and process elements in place, maintaining configuration control and exact role definition for employees to support the transformation process would be nearly impossible. Every team member within Toyota has a fluid understanding of his or her role in supporting the system and how each employee can work to improve the company's performance through the relentless elimination of waste. Whether benchmarking Toyota's Georgetown facility, NUMMI, or its production sites based in Japan, one thing has always stood-out. That is the company and its employees at all levels are serious about the TPS and its guiding precepts; they demonstrate and work hard to exude the passion and follow-through required in implementing large-scale, system-of-systems improvements. To clearly illustrate this point, the aerospace OEMs adopting the TPS would need to understand that the transformation process, by taking a holistic perspective, cannot be achieved overnight. This would take a relatively long and sustained effort, involving the deployment of an organic approach spurning largely incremental improvements that would help the OEMs to inch along towards the desired future-state.

In reality multiple facets of the transformation effort would be implemented concurrently during all aspects of the implementation effort. Implementing the TPS is not going to be as easy as reading Shingo Shingo's, *A Study of the Toyota Production System*, Taiichi Ohno's, *Toyota Production System – Beyond Large-Scale Production*, or, for that matter, reading this thesis, if the expectation is capturing the key points, drafting a plan, and expecting to achieve the TPS within a year to three-year period. It is not a flick of a switch and the light goes on; however, through the learning organization approach, fluid execution of tactical plans and demonstrated due-diligence to build collaborative advantage and mutual trust-based relationships, the light will go on, and once it does and illuminates fully the DNA of the OEM and its parts suppliers the opportunities will be nearly limitless.

6.1 Important Research Findings

A number of very interesting research findings I have garnered while writing this thesis include the following: (1) the importance of creating supply chain networks to build collaborative advantage, (2) the importance of the learning organization approach to incrementally eliminate waste from the system: and (3) the formal process of enterprise change and transformation needs to be supported with robust processes, tools, and guiding management principles.

In the commercial aerospace industry a predominant amount of supply chain related work is done through traditional arms-length relationships. In many instances senior managers and executives representing procurement, engineering, and manufacturing and assembly do not know their executive peers in the supply chain network and vice versa from the vantage point of the suppliers as important stakeholders. In fact, many suppliers in the commercial aerospace industry have not been to one of the OEMs facilities to see how their parts are installed on the airplane in the various programs they support.

Toyota's leverage of supplier associations would definitely provide a very good benchmark for the commercial aerospace industry to adopt. This could be done at the value stream level of an airplane program, through multiple programs with common value stream partners, and at the OEM-level (annually). While the associations would provide a very good platform for the OEMs to work with partners to tactically work to take waste out of the system I believe the true value they would bring would be creation of a forum for building close relationships and for cultivating and reinforcing trust throughout the industry. As Toyota has demonstrated with its supplier network, when utilized properly they can create very strong bonds and partnerships centered on the premise of building trust that drives collaborative advantage throughout the value stream.

As I have strongly noted in my conclusion summary, the development of a learning organization is of paramount importance in successful employment of the TPS concepts and practices. Before writing this thesis, I had often downplayed the importance associated with the "learning" process. Although I have been taught by some of the initial members of Taiichi Ohno's continuous improvement study teams, I had often overlooked the importance of their teachings pertaining to "watching", "observing" and learning from the system.

I'm not sure if it is a Western trait, or just part of my DNA, but I have always wanted to immediately jump to problem resolution in trying to improve the process. I was astonished to read, while I was writing this thesis, that even with all his duties in Georgetown, Fujio Cho would spend a significant amount of his time on the production floor observing, learning, and coaching continuous improvement with the company's employees. I have taken this as a great learning and will incorporate the practice into my daily management responsibilities.

On the surface the TPS seems like a simple system approach to achieve continuous improvement. While writing this thesis, I went into great detail outlining the *14 Management Principles* Jeffrey Liker details in *The Toyota Way.* While this discussion was presented at a fairly high level and maybe does some injustice to masterful articulation that Mr. Liker has presented in his book, my intent was basically to highlight the relevance these management principles have pertaining to how the system performs. The principles offer a robust structure, a set of tools and role validation for employees within the system, while providing an environment of ownership in the system's continuous improvement processes. As employees working in the TPS see improvement opportunities, they are expected to implement the improvements. As a result, the improvements contribute to the cultivation of the holistic system. Every improvement that is achieved matters and waste is not accepted, thus, as it shows its evil face, waste in its various forms is quickly eliminated from the system.

6.2 Important Areas for Future Research

After writing this thesis, I believe there are two very interesting questions suggesting future research opportunities: (1) how does Toyota perform its detailed hoshin planning, and (2) which major commercial aerospace OEM will collaborate first with Toyota, to form the NUMMI of aerospace manufacturing?

While there are some absolute gems that outline *hoshin* planning and how it is used, even by Toyota, to my knowledge how Toyota conducts its long-term and annual hoshin planning practices is not generally well documented. Based on my research, the fact that Toyota leverages tactical planning in its system-of-systems processes was extremely evident. There is no doubt that Toyota is methodical in its approach to planning and, coupled with its learning organization approach, I believe it is far and away one of the most important factors that contribute to how Toyota motivates and rallies its employees to contribute to the system's overall performance.

Meanwhile, as an extension of the second learning opportunity noted above, I believe there is a need for further research focused on demonstrating how the adoption of the TPS within the commercial aerospace industry can be more explicitly defined and even validated.

For example, such research might focus on how one of the two major OEMs might effectively form risk-sharing supplier partnerships in launching one of its future derivative programs, by building on the lessons offered by Boeing's 787 program and Toyota's past experience, as well as by bringing to bear on this question the considerable recent empirical and theoretical research that remains to be tapped to good advantage. I cannot think of a better way to observe, simulate, test, and learn about the system approach. I genuinely believe the OEM that does this first will win the "race". This would offer an immense historic opportunity to one of the two major OEMs the opportunity to learn and become the premier commercial aerospace manufacturing and product development company in the world.

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