LEAN TECHNOLOGY DEVELOPMENT

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ABSTRACT

In today's corporate world, successful technology management is separating market leaders from laggards. Because technology is in constant change and what is state-of-the-art today will be obsolete tomorrow, it is not companies with the best technologies that ultimately succeed. Instead, successful companies are those that succeed in institutionalizing and sustaining an efficient technology development process. Moreover, this process must be continuously improved by applying new techniques and concepts to cope with the increasing challenges of technology management.

This thesis will explore the extent to which Lean principles can be applied in technology development and how they can contribute to achieving new technology development imperatives (fast cycle time, increasing number of technology introductions, etc.). In order to answer these questions, the thesis proceeds in a logical manner by decomposing the objectives of technology development into organizational solutions using Axiomatic Design. Then, Lean principles as they have developed within the Product Development Focus Team of the Lean Aerospace Initiative are mapped into the above decomposition. The research concludes that under some additional considerations, Lean principles do lead to the achievement of technology development objectives.

More, the above theoretical research is applied to a real world case: Technology development at Ford Motor Company. After an assessment of the current process, opportunities of improvement are identified and a leaner process is proposed.

Finally, issues and opportunities with OEMs-Suppliers partnerships for new technological systems development are studied. The objective was to formulate policies and make recommendations for a better management of technology supply.

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CHAPTER 1: INTRODUCTION

" A consensus is emerging that something fundamental has changed [in the economic system]"
Jorgenson and Stiroh, the American Economic Review

We are living in an era of rapid change. The changes that occurred in the world during the last century are perhaps more important and more dramatic than those of any other period of time. The speed of progress became dramatic during the industrial revolution with the invention of machines that made in a fraction of time the same products men used to produce in weeks and months. The second industrial revolution took place with the development of modern manufacturing (interchangeable parts and moving assembly lines).

Today, we are living the third industrial revolution era, where innovation is pushed to new records thanks to technology. But this revolution is different. Different because technologies are impacting every industrial process and every organizational structure, the progress is no more linear, it is exponential.

Today, technology is changing the way we produce, work, communicate, consume and ultimately live. By optimally managing technology and organizing the technology development process. Man is finally managing his own destiny. This thesis is a humble attempt to understand how technology can be better managed and implemented.

1. A TECHNOLOGY ERA

1.1. Foreword

The word "Technology" will be very frequently used in the thesis. Even though it has become a commonly used word, it lacks a precise definition. For the matter and the context of this thesis, it will be defined as follows:

The term technology refers to the process of "transforming basic knowledge into useful applications. Science may be thought of as know-what and technology as know-how, while markets or businesses focus on know-what and know-who."[1] The know-how is used to improve a component, a feature, a product or finally an entire industry. The difference between revolutionary and evolutionary technologies should also be highlighted. The firsts are radical (the human genome mapping for example) and can change an entire industry or create entire different markets for new products. They can also change the competitive landscape of an industry through the emergence of new players, the disappearance of others and metamorphose of some others who managed to survive the technological shift. The second technologies are less radical. They can appear in the form of a new feature introduced in an existing product (the introduction of the airbag in the automobile for example.)

An emphasis has been put during the last decade on radical new technologies and their impact. Several books have been written in the past years exploring the virtues of radical innovation and technology development. This includes Richard Forester's Innovation: *The Attacker's Advantage* (Summit Books, 1986), Geoffrey Moore's *Crossing the Chasm* (Harper, 1991), James Brian Quinn's *Innovation Explosion* (Free/Press, 1997), and more recently Clay Christensen's *The Innovator's Dilemma* (Harvard Business School Press, 1997). While the importance of radical innovation is recognized in today's time of rapid changes, the importance of gradual innovation and evolutionary technology development should not be ignored simply because evolutionary are developed more frequently than revolutionary technologies. More, even if these technologies appear to be simple to manage, many managers struggle with how to scan, experiment and integrate new evolutionary technologies into their existing products and into new products.

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[1] Day, George and Schoemaker, Paul, Wharton on Managing Emerging Technologies, 2000.

1.2. First Agriculture, Then Manufacturing. Finally Technology

Since his appearance on earth, Man has been always looking for new opportunities to produce more by using fewer resources. Agriculture was one of his first initiatives in this regard. Agriculture has been in itself a way to create value by multiplying input through physical effort. With the development of tools, humans have been able to increase dramatically the use of the soil while reducing the amount of physical effort required for obtaining the same output.

With the industrial revolution and the invention of machines, it became possible for men to use more efficient sources of energy. The manual and horse powers have been replaced by the power of water, steam and diesel. Productivity increased phenomenally and the cost shifted from men to materials. Although the shift wasn't radical, the human cost fraction was reduced. Two other innovations: interchangeability of parts and the moving assembly line reduced the human cost in production. The interchangeability of parts reduced the need for costly experienced operators and made workers as interchangeable as the parts themselves. The moving assembly line reduced the waste in motion allowing the workers to perform more adding value tasks.

Technology is shifting the balance of costs another time. When taking today's products and analyzing the origins of their costs, the largest cost fraction doesn't go to manufacturing or materials; instead, it goes to the development of the product and the development of the technology that lies behind it. More, in the case of some products, the cost of manufacturing is a very small fraction of the technology development cost. This is the case for example with semiconductor products, where the highest fraction of the product value is created at the engineering and design of the chip architecture, not at the chip manufacturing level. Technology has emerged as a predominant way for value generation in the production process. Manufacturing is becoming ubiquitous and is being reduced to a non-strategic activity that can be outsourced to a third party without risking the firm core competencies. All these factors are completely changing the way companies do business, not only internally but globally as well. Today, it is recognized that over the coming decades, the western countries will move from manufacturing to knowledge and technology and that all manufacturing activities that require low knowledge but huge labor expenses will be moved south to countries that have the advantage of cheap labor and available raw resources. This phenomenon has already occurred years ago with the textile industry where labor cost is very important but it will inevitably spread to other industries. These factors are resulting into a competition shift: It is no more manufacturing system against manufacturing system, or supply chain against supply chain. It is technology against technology and innovation against innovation.

2. THE EMERGENCE OF LEAN

2.1. Definition of Lean

> "Becoming lean implies a journey. We will reach our destination when we apply the philosophies underlying lean to develop our own lean systems. There's no reason not to start trying. There are no experts, just people with more experience. The longer we wait, the more experience our competitor will have when we start."
>
> John Y. Shook, Director, Japan Technology Management Program, University of Michigan.

There is not a unique definition of Lean. Even at Toyota where the principles of lean first emerged, managers and engineers think that Lean has to be lived and can not be defined. However, for the purpose of the thesis, Lean transformation will be defined as the process of eliminating all non-adding value steps from the underlying process. Only the steps that add value to the final output or the steps that are necessary, even if they are not value adding are kept. Therefore a process after Lean transformation requires less resources and less time to produce output of higher quality.

2.2. Brief History of Lean

2.2.1. The Birth of Mass Production Systems

The industrial revolution changed completely our understanding of production. With the invention of steam machines, manufacturers were freed from their dependence on man or horsepower, opening up far greater freedom of location and industrial organization. This freedom allowed reaching cheaper labor and materials, which led to lower production costs, lower prices, and greatly expanded markets. However, the emergence of mass production systems as known in the 20th centuries depended on two main innovations: (1) Vertical integration and (2) Interchangeable parts. It is difficult to overstate the importance of the idea of interchangeable parts; Boorstein (1965) calls it "The greatest skill-saving innovation in human history"[2]. This concept greatly reduced the need for specialized skills on the part of the worker. Workers became, like parts, interchangeable

In the beginning of the 20th century, another innovation took place: Ford (1863-1947) introduced high-speed mass production of complex mechanical products using the moving assembly line: "The thing is to keep everything in motion and take the work to the man and not the man to the work. That is the real principle of our production, and conveyors are only one of many means to an end." (Henry Ford, Today and tomorrow, p.103)

Ford built his strategy around providing cheap reliable vehicle. In 1908, he proposed the legendary Model T and priced it at $850. By focusing on the on continual improvement of a single model and pushing his mass production techniques to new limits at his Highland Park plant, Ford reduced labor time to produce the Model T from 12.5 hours to 1.5 hour, and brought down the prices to $290 by 1920s. By the early 1920s, Ford Motor Company commanded two-thirds of the American automobile market.

A main success factor of Ford plans was his strategic appreciation for the importance of speed. He understood early the importance of speed in the reduction of cost and throughput. In 1926, he boasted that his company could take ore from a mine and produce an automobile in 81 hours. Given this, even Taiichi Ohno, the originator of lean concepts was an unabashed admirer of Ford. However, the Ford system worked well only when the demand was enough to absorb all produced cars and only when there weren't any varieties (or a reduced number of varieties) in the final product. In the other cases, the Ford Production System was unable to react adequately to variations:

> "Ford made a dramatic wrong turn at his Rouge complex, He maintained the assembly track but rearranged his fabrication machinery into process villages. He proceeded to run a push schedule in which growing fluctuations in end-customer demand and persistent hiccups in upstream production were buffered by a vast bank of finished units forced on the dealer network and equally vast buffers of parts at every stage of production upstream from assembly. Thus "flow" production (as Ford termed it in 1914) became "mass production".
>
> James Womack[3]

2.2.2. The Japanese Modern Approach to Production

A lot of customers accused the Japanese of lack of originality and pointed to their "faceless" cars that looked alike. A designer at BMW once said: "take the badge from a Toyota, a Nissan and a Honda, and you will be unable to recognize one from another." This was not very flattering for the Japanese and was certainly true in the seventies and the eighties. But what this designer didn't know is that Japanese designers were working in close coordination with their peers from manufacturing and were designing the body in a way that its parts should arrive to their final shape within less than three passes under the dies. The objective was to make savings on the dies. Meanwhile the big three were producing less appealing cars with up to seven passes under the dies in some cases.

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[2] James Beginer, The Control Revolution, Harvard University Press, 1986.

[3] Foreword to: Becoming Lean, edited by Jeffrey Liker (Portland, Oregon: Productivity press) 1997.

The same practices can be noticed today in 2001. For example, Toyota has only one Toyota badge used on all its models from the most compact car to its biggest truck. While Ford with relatively the same range of models has fifteen. Still, customers never remark this difference in the design of this detail. Happily, it creates huge savings for Toyota.

These examples and several others, show the philosophy behind the Japanese vision of modern manufacturing and product design. In reality, the origin of the philosophy reflects back to post World War II era, when Japan was economically devastated and production resources were very scarce. During that period the objective was to achieve superior performance using the least resources. Lean concepts were developed over a period of several decades as counter measures to Japanese situation. They were based on two main principles (1) Standardization of work, information flow and support in order to be able to identify perturbations as soon as they occur and (2) Continual improvement of work methods and processes to achieve higher performance measures.

2.3. Lean as a Scientific Approach to Problem Solving

Perhaps the best explanation of Lean that can be found in the literature is Spear's *Decoding the DNA of Toyota Production System (TPS).* According to Spear, TPS is described as being built upon the foundations of the scientific method—observation, hypothesis, formulation, prediction of results, and performance of experimental tests—as a means to provide a reliable, consistent and non-arbitrary methodology to design and improve upon manufacturing processes.

In explaining why so many companies find it difficult to develop Toyota-like production systems, Spear points out that TPS is a system that grew naturally and largely unwritten over the course of five decades. Nevertheless, he believes that the workings of TPS can be captured by the following four Rules:
Rule 1: All work shall be highly specified as to content, sequence, timing, and outcome.
Rule 2: Every customer-supplier connection must be direct, and there must be an unambiguous yes-or-no way to send requests and receive responses.
Rule 3: The pathway for every product and service must be simple and direct.
Rule 4: Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organization.

Each of the above rules requires that problems be identified automatically by built-in feedback signals for each and every activity, connection, and flow path. The rules are also believed to create a nested, modular organizational structure—a structure that allows Toyota to introduce changes and improvements to its operations while remaining stable at the same time. Finally, the originality of the four rules stems from their wide range of applications, not only to material processes but to information transformation as well. This will be very useful when considering lean technology development and deployment. A new technology is, after all, as it has been defined, the process of transforming information from the pure science state to a useful application state.

3. RESEARCH OUTLINE

3.1. Motivation

Technology innovation has always been a risky process, and the history of corporations is full of examples where technologies that first appeared to be very attractive but then failed to attract customers and were quickly withdrawn from the market. But at today's pace of technology development and introduction in the market, not innovating is riskier than innovating itself. Competition is no longer brand against brand, or price against price, it is technology against technology. Based on this requirement for innovation and the introduction of more and more technologies, this research seeks to explore Lean as an enabler for the achievement of these requirements. The thesis evaluates in what measure technology strategy, technology cycle time, technology organization and integration, along with other functions in the company, can be improved using Lean principles.

3.2. Key Questions

"How can we transform the requirements in terms of technology strategy into attributes of the company and then build the enablers that allow the company acquire these attributes?" is probably the first question one would ask when witnessing the accelerating pace of technological innovation. Every company selects the technology strategy that best fits its market orientation and its culture. Each of these strategies has different translations in term of attributes and enablers to be built in order to achieve these requirements. Our purpose is to study in which measure can Lean technology development and deployment be an enabler for the requirements of technology strategy. Key questions include: What are today's global trends in technology? Can Lean be the solution to technology challenges? How can lean technology development and deployment be implemented? What does it imply in term of organizational changes?

3.3. Methodology

Unlike traditional research, this thesis does not rely on data analysis out of which all results should follow. On the contrary, it is an attempt to shed the light on a subject that is in today's world at the heart of corporate strategy. Although this subject has attracted several researchers and writers in the last decade, the focus has been mainly on building new strategies and approaches for technology and finding solutions for new technologies integration. A very limited amount of research that directly links technology strategy to implementation and organization has been found. The first milestone for this research is to summarize how innovation strategy can be effectively translated into successful implementation.

Studying how Lean principles can contribute to the achievement of technology strategy and developing a methodology for lean technology development will be the second milestone of the research.

The third milestone of the thesis was the application of the results that have been concluded from the research to a real world case: New technology development and Deployment at Ford Motor Company.

3. CHAPTER OUTLINE

CHAPTER 2 introduces the new trends in technology and identifies five trends that are affecting the way companies manage technology development. CHAPTER 3 presents the axiomatic design methodology. CHAPTER 4 draws on CHAPTER 3 to build a Technology Decomposition where the strategic objectives of technology are linked to the operational solutions designed to achieve them. CHAPTER 5 tries to answer the main question of the thesis by presenting first the Lean Engineering Framework and the Lean Principles that were developed within the LAI and mapping them into the Technology Decomposition. CHAPTER 6 discusses a case study where the approach studied in CHAPTER 5 is applied. Finally, CHAPTER 7 assesses suppliers' policy issues and makes recommendations on how to manage technology development partnerships with suppliers. In the end, major findings are summarized and possible directions for future research are discussed.

CHAPTER 2: TECHNOLOGY TRENDS

> "Technology can be a powerful weapon on the battlefield of economic enterprise"
>
> Alan L. Frohman

1. INTRODUCTION

The last decade saw the emergence of several trends in technology. Some of these trends are linked to the globalization of the world economy, which pushed competition to a global level and intensified it. In addition, the development of new tools such as networks, the Internet, computers processing power, etc., is making possible technological innovations that were impossible before.

In this chapter, we will study in detail the global technological trends that are affecting companies and completely changing the role of technology in the design of companies' strategy. The focus will be on the particular following factors:

(1) The ubiquity of technology tools.
(2) The proliferation of technologies relevant to any product.
(3) The emergence of a multitude of transformation and process-related technologies.
(4) The increase of technology introductions.
(5) The decrease in technology development cycle time.

In a second part, we will identify some of the organizational evolutions that are taking place along these global trends in technology development. The study of organizational solutions to deal with efficient technology development will be looked at in CHAPTER 4.

2. GLOBAL TRENDS

2.1. The Ubiquity of Technology Tools

In today's world, the tools for technology development are getting cheaper. From powerful computers, to machines that discover and synthesize DNA sequences in minutes and the powerful graphic workstations that allow the simulation of virtually every phenomenon, these tools are not only available, but are becoming cheap as well. This means in particular that one of what used to be natural barriers separating the cash-rich large corporations from cash-starving small start-ups has been eliminated. It is surprising to see how the power of a supercomputer from the eighties can be found nowadays in any home PC. It is also surprising to see how five times the memory of the Apollo lunar module can be found nowadays in a children's toy (Figure 1). If that means any thing for strategy, it would be a tough competition from virtually every player willing to develop a technology because the tools for that are available and cheap.

1969 Apollo lunar excursion module: 48 Kbytes ROM	2001 Rocket, the wonder dog (a dog toy from Fisher Price): 256 Kbytes ROM
1985 CRAY2 Super Computer: 1 billion floating point operations per second	2001 traditional PC: 1.8 billion floating point operations per second
1991 Space Shuttle: 1 MHz onboard computer	2001 Mercedes Benz S500: 100 MHz onboard computer
1991 Indigo 2 graphics workstation from SGI: 350,000 flat polygons per second	2001 Xbox game console from Microsoft: 125 million micro polygons per second
1996 Deep Blue Chess playing super computer: 200 million moves per second, 1.4 tons	2008 Tabletop chess game: 1 billion moves per second (estimated), 3.2 pounds.

Sources: Cray, Fisher Price, IBM, Intel, Mercedes-Benz, Microsoft, NASA, Sanrio, SGI, Wired research

Figure 1: The Ubiquity of Technology Tools

In addition to this factor, another one having the same effect is taking place: the dissemination of expanding scientific knowledge worldwide. Twenty years ago, it was estimated that more than 80% of worldwide graduates (with a Bachelor, a Master or a Ph.D.) originated from four regions of the World: Europe, Japan, North America and the ex-USSR. Today this number is estimated to be in the range of 50 per cent and in the coming ten to twenty years, this number is estimated to be in the range of 20 per cent. This worldwide dissemination of knowledge coupled with cheap labor cost (even engineers and scientists) in developing countries means that technologies can be developed from totally unexpected players.

The ubiquity of technology tools appeared also in a study made by Sloan School of Management Professor Roberts during his survey of technology strategy in Japan, Europe and North America, as shown in the following table. More and more companies understand that technology can be developed by outside providers. For example, in the United States, the proportion of companies relying on outside sources of technology has jumped from 10% to 85% in less than a decade. This behavior comes from the fact that new players with adequate competencies are able to offer better technologies than the ones offered by in house development.

	1992	1995	1998	2001
Japan	35	47	72	84
Europe	22	47	77	86
North America	10	30	75	85

Source: Edward Roberts, Corporate Entrepreneurship: Strategies for Technology Planning and Business Development.

Figure 2: Percentage Companies with High Reliance on External Sources for Technology

2.2. A Proliferation in the Number of Technologies Relevant to Any Given Product

In today's rapidly changing world, it is not technology that is developed to satisfy an identified need; instead, it is technology looking for new applications in all possible domains. Competition may come from unexpected players who have never been in the same domain of the original provider, but found that the technology they have developed have applications for the product of the incumbent. The most striking example of this phenomenon is the case of IBM, which developed the first original PC. IBM started looking for diversification developing all possible equipment that needed the processing power of a PC. Although, several trials have been failures, IBM succeeded in creating a place for itself in industries that were not related to the personal computer at the first sight. Among IBM trials were: The copier industry where IBM entered in competition with Xerox, the Satellite launching services, medical equipment, scientific equipment and several other ventures. In the medical equipment for example, IBM believed that medical equipment could be easily created by adding some sensors and peripherals to a personal computer. This approach worked for a while with devices that required a minimum level of sophistication, however, the same approach failed miserably when the equipment became more sophisticated.

Today the same approach is being used at a larger scale, and in particular by companies in mature markets who want to invest in new emerging, more promising and more profitable markets. For example, Intel exited, successfully, the commoditized market for memory chips, took the leadership position for processors and is now entering a relatively unrelated market: personal media devices such as MP3 players, digital cameras, personal digital assistants, etc. Microsoft is another example of a company who is entering and successfully taking the lead of a relatively unrelated industry, i.e., from the business of desktop software to networks and Internet related tools.

2.3. Diverse and Transforming Process Technologies

Process technologies do not only create competitive advantage for their own in term of more efficient processes, they also dramatically enhance other technologies' competitive advantage. This can be seen for example in term of reducing time to market as well as manufacturing system preparation time. As it be will be seen throughout the thesis, the Internet and information systems have been one of the main technologies transforming internal development and integration processes inside companies.

Through email, online project management tools, knowledge management tools, the work procedures and management processes have completely changed. Although the advantages of process technologies are multiple, the main ones can be summarized as follows:
(1) Reduction of the entire technology cycle
(2) Rapid integration of customer requirements feedback
(3) Increase in design capabilities through the emergence of new processes that were not available before.
(4) Increase in the productivity of development teams.

In the automobile industry for example, the Japanese have been able to make the dies in a time less than half the time required for the Americans to make similar dies. This stems from the process used to design and supply the dies. Through information systems linking and integrating the design teams and the dies' suppliers, Japanese can produce dies that satisfy the product requirements in a matter of days.

2.4. The Increase and Acceleration of Technologies' Introduction

In today's world, Original Equipment Manufacturers (OEMs) are struggling in the heart of intense competition from a multitude of players. In this regard, technology is used as an effective way for differentiation. In the case of the automobile industry, and with the multiplication of models in a mature market, it is recognized that additional features that are added to the car in the form of new technological systems that provide additional value to the user are becoming unique selling points. In a study done by Toyota in the eighties, more than 3000 features that may be relevant to the car user were identified. These features included everything from the power of the engine to the shape of the door locks. Among these 3000 features Toyota selected and focused its development on the twenty more important features. Today almost all manufacturers have made astonishing progress in these main features such as quality, price and rapid delivery. Therefore, competition is moving to other features that used to be less important, but that are becoming more and more important to the customers and the OEMs. These used-to-be less important features are today's technological systems that we are starting to see in cars. If we take for example a model like the Mercedes S class, it saw the introduction of more than 15 new technological systems. This includes the Distronic Adaptive Cruise Control that, thanks to a radar sensor installed in the grille, pinpoints the location of a moving car ahead, then automatically adjust the throttle –and even applies up to 20% of the car braking power – to help the driver maintain the following distance he has selected. The Active Ventilated Rear Seats where inside each seat are installed 10 miniature fans that draw cooling air from underneath the seat through perforations in the leather-seating surface. Three stages of cooling help the passengers keep more comfortable. The Electronic Trunk Closer, which allows the user to electronically close a fully open trunk lid without touching it. By pushing a button in the cabin or inside the trunk, the lid closes itself. The Infrared Reflecting Glass, that helps reduce radiant heat penetration and therefore keep the cabin cooler.[4]

These technological advances are not yet in every automobile and are restricted to luxury cars. However, it is just a matter of time. An example would be the case of the car radio. Sixty years ago (in the thirties), this product appeared on the market as a feature on luxury cars. Allowing only mid and long wave mono reception, it sported the weight of a grown up passenger and cost $1,000 in present day currency. Today it has evolved into a standard feature that every motorist expects to have in his car. It has several characteristics unheard of at the time of its first introduction (hi-fi sound, search features...) and sells for about $75.[5]

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[4] From Mercedes website @ www.mercedes.com

[5] Launching new product features: a multitude case examination, Journal of Product Innovation Management, 2001

2.5. A Fast Technology Cycle Time

"Time is of the essence...In many industries, even six months can be packed with moves and counter moves. Products are born, sold, and phased out. Information moves very quickly. Customers will not wait; indeed, they will pay a premium for responsiveness"[6]

The advantages of fast technology introduction are multiple. It distances the firm from competition through faster learning and greater proliferation of technologies in the marketplace. The example of residential air conditioners illustrates the importance of technology fast cycle development in gaining market leadership. Mitsubishi Electric introduced new technological innovations four times faster than its American competitors and won, along other Japanese manufacturers, the American market in a matter of a decade. As late as 1979, the technological sophistication of the Mitsubishi air conditioner was roughly equal to that of the U.S. competition. This was before Mitsubishi innovation obsession of the eighties. In 1980, it added to the product integrated circuits to control air-conditioning cycle. One year later, the company replaced the integrated circuits with microprocessors and added two other important innovations to increase consumer demand. The first was "quick connect", which simplified the assembly and installation of the product. The second innovation was simplified wiring. On the old product (and still today on the U.S. product) the unit had six color-coded wires to connect. The advent of microprocessors made possible a two-wire connection with neutral polarity. These two innovations did not improve the performance of the product, nor were they intended to. Rather, the objectives were reliability and easy installation and maintenance. In 1982, Mitsubishi introduced a new technological advance: a high-efficiency rotary compressor replaced the outdated reciprocating compressor. In 1983, Mitsubishi added sensors to the unit and more computing power improving efficiency. In 1984, Mitsubishi introduced another technology, the inverter, which allowed unparalleled control over the speed of the electric motor, dramatically, boosting the appliance's efficiency. Incrementally and through fast technology introduction, Mitsubishi and other Japanese companies on the same track gained technological and market leadership.

In 1985, a U.S. air-conditioner manufacturer was just debating whether to use integrated circuits in its products. In view of its four to five year product development cycle, it could not have introduced the technological innovation until 1989 or 1990 putting the American company ten years behind Mitsubishi. Faced with this situation, the American air-conditioner manufacturer found no choice but to source its air conditioners and components from Mitsubishi and other Japanese companies.[7]

Thirty years ago, managers believed that reducing the cycle for technology development could only be done by sacrificing other attributes of the technology such as the performance and the reliability of the technology. However, in recent years this trade-off has disappeared. With the emergence of new processes for research and experimentation such as the use of computer simulations, it is now possible to achieve all technology attributes, including fast cycle time, in the same time.

3. TECHNOLOGY IN THE ORGANIZATION

If technology has emerged as a way for creating key competitive advantage, it is also impacting the corporate organizations and, at the heart of these organizations, the teams in charge of generating new technologies. Technology is no more a black box for managers. Top managers are approaching scientists and engineers and helping them ask questions about customers and competitors. How will needs change over the next five years? What are the competitors likely to do? Where do we need to be? What are the technical alternatives? What capabilities do we need to build? Where should we focus our resources?

A study made by Edward Roberts from Sloan School of Management, in the end of the nineties, shows how corporations are reacting to the trends in technology and innovations (Figure 3). In less than a decade:

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[6] Clark, K., What Strategy Can Do For Technology, HBR, 1989

[7] Stalk, G., Time-The Next Source of Competitive Advantage, HBR, 1989

(1) Central corporate research has replaced joint ventures and alliances in the second place. This shows at which extent corporations are approaching technology more seriously and placing research departments near top management positions. This fact shows also that technology is emerging as a competitive advantage. Companies prefer to rely more on central research than on joint ventures and alliances, which oblige companies to share their technologies and add to the uncertainty because of external sources of risk.

(2) Incorporating suppliers' technology has also overtaken joint ventures and alliances as the third source for development work. Suppliers have increased their research capabilities and are using the technologies they are developing to sell their products. In addition, suppliers have a very important advantage in comparison with alliances and joint ventures partners, their complete knowledge of their users' products as well as the final customers' needs (through their users). This knowledge of the products that will incorporate the technology coupled with their competencies in research and development allows them to play a key role as technology providers. This evolution will be studied further in detail in CHAPTER 7.

(3) Consultants and contract R&D have been moved completely from the top 8 sources of development work. This is an additional argument in favor of the fact that companies are taking technology more seriously than in the past.

1992	1999
1. Internal R&D within divisions	1. Internal R&D within divisions
2. Joint ventures/alliances	2. Central corporate research
3. Central corporate research	3. Incorporating suppliers' technology
4. Incorporating suppliers' technology	4. Joint ventures/alliances
5. Licensing	5. Licensing
6. Acquisition of external technologies	6. Incorporating customers' technology
7. Acquisition of products	7. Continuing education
8. Consultants/contract R&D	8. Acquisition of products

Source: Edward Roberts, Corporate Entrepreneurship: Strategies for Technology Planning and Business Development.

Figure 3: Rank-Ordered Importance of Sources for Development Work

4 SUMMARY

CHAPTER 2 showed the global trends in Technology: The ubiquity of technology tools, the proliferation of technologies relevant to any product, the emergence of a multitude of transforming and process technologies, the increase of technologies introductions, and finally, the decrease in technology development cycle time. If these trends show something, it is the paradox of technology as explained by Kim Clark: "Technology has never been more important, yet building a competitive advantage by means of technology alone has never been more difficult...But technology cannot be management's primary solution because it is every competitor's potential solution. A good offense can seem to be only defense. It is nearly impossible to build a lasting edge through a unique device developed by R&D or through an innovative, computer-driven process"[8]. Based on these trends, competitive advantages are shifting from technology itself, to the management of the very same technology. Companies that will flourish in the future are not the companies with cutting edge technology (because the competitors will inevitably develop similar or better technologies), but companies that manage these technology and innovation processes well to sustain their lead. In the next chapters, the requirement for successful technology management, in particular using Lean concepts, will be discussed in detail.

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[8] Clark, K., What Strategy Can Do For Technology, HBR 1989.

CHAPTER 3: AXIOMATIC DESIGN AS A TOOL FOR SYSTEM DESIGN

1. INTRODUCTION

In this chapter, the axiomatic design methodology will be introduced and its principles will be discussed. This methodology was developed at the Massachusetts Institute of Technology by Professor Nam P. Suh [Suh, 1999] to give systems developers a logical, structured and scientific approach when selecting and developing the best solutions to achieve the objectives and targets of a system.

The steps involved in the axiomatic design include the conversion of customer requirements and wants into functional requirements for the system. Then process and organizational solutions (DPs) are selected to achieve the functional requirements (FRs).

From a technology point of view, the objective from the axiomatic design principles is to build a framework that links the functional requirements of research and development organizations to the operational solutions (organization, tools, procedures, processes, etc) that need to be put in place in order to achieve technology development imperatives. The application of the axiomatic design methodology to technology development will be discussed in the next chapter where a Technology Decomposition will be created.

2. CUSTOMER, FUNCTIONAL AND PHYSICAL DOMAINS

The FRs state *what* the objective is, and the DPs describe *how* those objectives are achieved. Suh divides the design into four domains: the customer domain, the functional domain, the physical domain, and the process domain. Continuous interactions between these four domains are necessary in order to achieve the initial objectives from the design. The Technology Decomposition that will be proposed in the next chapter takes into account the first three domains of design. Figure 4 describes how the customer requirements are converted into functional requirements, and these in turn are translated into design parameters that describe the operational implementation of the requirements.

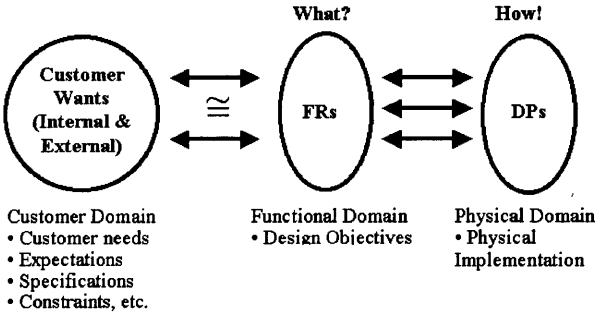

Figure 4: Interaction Between Three Domains of the Design (Customer, Functional, Physical)

The identification of high-level customer needs and wants is the start of axiomatic design process. Once the customers needs have been identified, for example, this need can be in the form of having a coherent and value creating technological strategy. This need can be converted into a high-level functional requirement, for example technology strategy that meet internal and external customers imperatives. Finally, this high level FR is mapped into a design solution that allows the achievement of the high level FR.

3. ZIGZAGGING METHOD OF DECOMPOSITION

The selection and synthesis of DPs is usually a very demanding process. At high levels, the DPs may be conceptual and abstract to the point where the system-solution to the high level objectives is described but without sufficient information to implement the system. In order to arrive at an explicit solution (and not only a description of the system-solution) decomposition of high-level FRs into lower level FRs is required. The DPs of low level FRs are enough explicit and contain enough information for the system to be implemented. This method is called the zigzagging method of decomposition and can be seen in Figure 5:

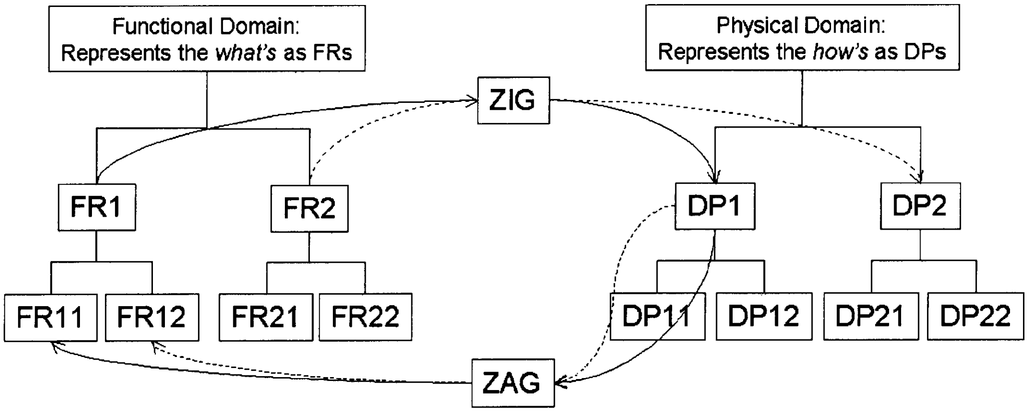

Figure 5: Zigzagging Method of Decomposition

Normally, the decomposition should continue until the low level DPs are completely explicit and can be implemented at an operational level.

4. DESIGN MATRICES AND GRAPHICAL REPRESENTATION OF FR-DP RELATIONSHIPS

A major advantage of axiomatic design is the graphical representation of the relationships between FRs and DPs, which are usually shown in the decomposition with a solid line (if the DP has been developed to respond directly to the FR) and with a dotted line (if the DP affects other FR which it wasn't originally developed to respond to). These relationships are generally expressed using design matrices as in equation (1):

$$(FRs)=[A](DPs) \tag{1}$$

Where (FRs) is the vector composed of different FRs of the same level of the decomposition, (DPs) is the vector composed of the DPs that have developed to satisfy the above FRs (They are therefore at the same level as well). In this case the design matrix $[A]$ indicates the relationships between the FRs and the DPs and show how the DPs affect different FRs. For example, the following design equation contains a 3x3 matrix with two kinds of elements:

$$\begin{pmatrix} FR_1 \\ FR_2 \\ FR_3 \end{pmatrix} = \begin{bmatrix} X & - & - \\ - & X & - \\ X & X & X \end{bmatrix} \begin{pmatrix} DP_1 \\ DP_2 \\ PD_3 \end{pmatrix} \tag{2}$$

The element X (respectively -) of the design matrix $[A]$ shown in equation (2), indicates the existence (respectively the absence) of a relationship between a DP and the corresponding FR (For example A_{11} indicates that DP_1 affects FR_1, while A_{21} indicates that DP_1 does not affect FR_2) [Tate, 1999]. The above matrix expression can be represented graphically as follows:

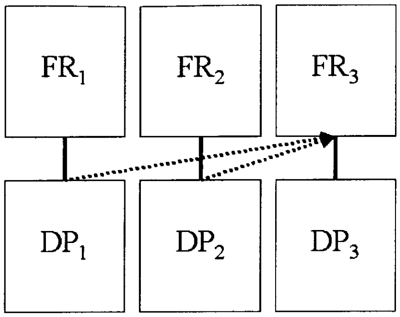

Figure 6: Graphical Representation of the Decomposition in Equation (2)

5. INDEPENDENCE AND INFORMATION AXIOMS

As explained above, several solutions can be found achieving the same FRs. In order to deal with this situation that may be faced by system designers, Suh developed two axioms that need to be satisfied in order to select the best set of possible design parameters (DPs) and therefore develop a good design [Suh, 1999]. These axioms are known as the Independence Axiom and the Information Axiom:

(1) The Independence Axiom specifies that an acceptable or good design must maintain the independence of all functional requirements as a result of the selection of the DPs. In this case, satisfying a particular FR should not affect the feasibility of achieving other FRs. In the best-case scenario, the DP for an FR can be adjusted without affecting other FRs. If this is not the case, then one or all the DPs infringing on the other FRs should be reformulated to eliminate the interdependency. It must be noted that the independence axiom refers to the achievement of functional independence and not of physical independence. DPs can be dependent and still achieve separate FRs.

(2) The Information Axiom states that the information content of the design must be minimized. Designs with the highest probability of success are the designs that require minimum information content therefore given two uncoupled designs, the simpler design is preferred to the other one because it is more robust and has higher probability of success. This axiom deals with quantifying the complexity of solutions, which can be very difficult to perform when dealing with concepts at a high level. For the purpose of the thesis, this axiom is discarded when decomposing high-level functional requirements.

6. DESIGN AND COUPLING

Professor Suh identified three different kinds of design depending on the shape of the design matrix. These kinds are uncoupled design, partially coupled and coupled designs. They can be defined as follow: When each DP affects one and only one FR, the design is said to be uncoupled, in this case the design matrix is diagonal (or FRs and DPs can be interchanged in a way that the matrix becomes diagonal). The functional independence is attained in this case. This means in particular that all the FRs can be achieved simultaneously.

When some of the DPs (but not all the DPs) affect not only their corresponding FRs but other FRs as well, the design is said to be partially coupled. In this case the rows and columns of the design matrix can be interchanged such that the matrix is lower triangular. If the most influential DPs (the ones that affect the maximum of FRs) are controlled first, than the functional independence can be achieved in this case as well.

When some of the DPs affect not only their corresponding FRs but also other FRs as well in a crossover structure, the rows and columns of the design matrix cannot be interchanged to form a triangular matrix, the design is said to be coupled in this case and functional independence cannot be achieved. The design matrices of respectively an uncoupled design, partially coupled design and finally coupled design are represented in figure 7:

$$\underset{\text{Uncoupled Design}}{\begin{bmatrix} X & - & - \\ - & X & - \\ - & - & X \end{bmatrix}} \quad \underset{\text{Partially Coupled Design}}{\begin{bmatrix} X & - & - \\ X & X & - \\ X & X & X \end{bmatrix}} \quad \underset{\text{Coupled Design}}{\begin{bmatrix} X & - & X \\ - & X & - \\ X & - & X \end{bmatrix}}$$

Figure 7: Uncoupled, Partially Coupled and Coupled Design Matrices

An ideal design would be one with an uncoupled design matrix. However, a design can achieve its FRs even if it is partially coupled but in this case the design is path dependent, which means that the DPs that affect the maximum of FRs need to be controlled first, then the others that affect a lesser number of FRs.

7. CONCLUSION

In this chapter, the main principles of the axiomatic design methodology have been presented. The originality of this approach, as we will see it in the rest of the thesis stems from its ability to link organically the strategic objectives of a process to its operational organization. This approach is particularly useful in the case of the research described in this thesis, which is the study of links between technology imperatives and technology organization using lean principles. In the next chapters, this methodology will be applied for this research objective.

CHAPTER 4: AXIOMATIC DESIGN AND TECHNOLOGY MANAGEMENT: LINKING TECHNOLOGY STRATEGY TO OPERATIONAL SOLUTIONS

"The advantage now often goes to the companies most adept at choosing technologies, not the companies that create them"[9]

1. INTRODUCTION

There are many reasons for looking at the link between technology development imperatives and the underlying implementation processes. As explained by Thomas Johnson, in his book, Profit Beyond Measure[10], it is the search for organic relationships between objectives and solutions that allows us to see the challenges of management rather than the focus on quantitative relationships, which reduces management problems (in our case, technology development issues) to only financial performance and quantitative indicators in term of development cost, time to market, etc. These quantitative parameters are important, and even very important. However, they cannot be influenced directly, simply, because if we do so, we lose other relationships in the development process that inevitably reduces the quantitative performance of the process itself. This includes quality, productivity, amount of rework, etc. For example, by putting the pressure on engineers to finish the development process on time, they tend to make more mistakes that translate in more rework and create new delays that ultimately delay the entire development project, which, in turn, prevents the achievement of the original objective. What we are saying here, is that instead of just putting pressure on engineers to finish the work on time, the project manager should try to understand the real organizational and operational problems that created the delay and try to resolve them, in order to, first solve the real problem instead of attacking its syndromes and, second, to avoid making the same mistakes in future projects.

The axiomatic design, which has been presented in the previous chapter, and through it functional requirements – development solutions approach enables us to understand the organic links between the objectives of technology development at a strategic level and the implementation solutions at an organizational level. By understanding these causal relationships and implementing the "right" set of solutions, the performance indicators will inevitably follow in a logical manner.

2. TECHNOLOGY DECOMPOSITION

As it has been explained in the introduction, there are many reasons to look for links between requirements for the development of new technologies and the operational solutions developed to achieve these requirements. Problems occur because the structure used to develop new technologies doesn't respond to the technology imperatives of the company. This is the case for example when the technologies being developed do not meet one of their imperatives: customer preferences in term of performance, cost, etc. Figure 8 shows the path followed by the technology development process in this case: redesign, modifications and withdrawal from the market.

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[9] Marco Iansiti, Jonathan West, Technology Integration: Turning Great Research into Great Products, HBR, 1997

[10] Thomas Johnson, Anders Broms, Profit Beyond Measure: Extraordinary Results Through Attention to Work and People, Free Press, 2000.

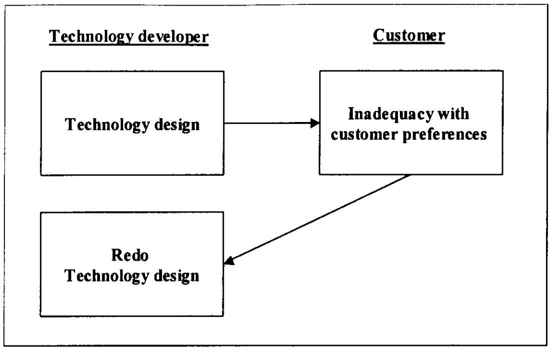

Figure 8: What Occurs When Technology Development Ignores Customer Preferences

The Newton, a first generation personal digital assistant (PDA) that was developed by APPLE in the beginning of the 90's, is a perfect example of this situation. The handwriting recognition technology that was developed at that time was very slow and performed miserably in recognizing the user writing. Since the technology didn't meet customer requirements and therefore his satisfaction, the product was a commercial failure and was withdrawn from the market in 1996. On the other side, the success of PALM in the same market where APPLE failed is largely attributed to the very successful handwriting recognition technology of its product (The PILOT), a technology that has been improved in the laboratories for years in order to ultimately meet the customer requirements in term of performance (speed, success rate, etc).

The Technology Decomposition described bellow was developed to understand how such failures could be avoided by clearly understanding what are the objectives from technology development and translating them at an operational level. It follows the axiomatic design methodology (axiomatic design [Suh, 1999]). The main resources used to develop this decomposition were interviews conducted with managers from Ford Motor Company and research performed at the Massachusetts Institute of Technology within the Laboratory for Manufacturing and Productivity where frameworks using the axiomatic design (such as the Manufacturing System Design Decomposition [Cochran, 2000] and the Product Development Design Decomposition [Bocanegra, 2001]) were decomposed.

At the very top level of the decomposition, FR-01 states the objective of the Technology Decomposition: "Technology development that meets technology development imperatives". These imperatives are dictated by global trends in competition and market and by different stakeholders such as shareholders, final customers, manufacturing, management, etc. Internal customers are defined as all the stakeholders within the organization (manufacturing, product platform teams, marketing, etc.). The design parameter (DP-01) for this FR is the Technology Decomposition itself.

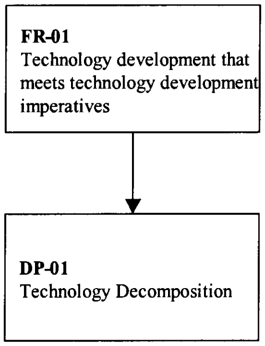

Figure 9: High level FR and DP of the Technology Decomposition

The various strengths of axiomatic design that have been discussed in the previous chapter and in particular the emphasis on the separation between the objectives and the means designed to achieve them as well as the separation between the objectives in an uncoupled manner lead to the creation of a very powerful framework for technology development management. This is especially helpful because when a technology is developed, the "product" is information and data, and not a physical part. Therefore, there are more people-people interactions in the technology development process compared to the interactions during physical product production. These interactions can easily interrupt the flow of the data when there is not a clear common mental model among different actors to achieve the objectives of the technology development process. The objective of the Technology Decomposition is to create exactly this mental model and put all the actors on "the same page", targeting the same objectives and developing the same solutions.
FR-01 was chosen because it takes into consideration all the technology imperatives, which may be in some times contradicting. For example, the external trends such as evolutions in the market may dictate the development of certain type of technologies, but internal customers to the company for technical, manufacturing or marketing considerations refuse the proposed set of technologies. In order to meet the imperatives of all stakeholders, technology development must meet five basic FRs as specified by the next level of the decomposition:
(1) Ensure coherent technology strategy.
(2) Design an applicable technology that satisfies the external customer imperatives.
(3) Reduce the overall technology development time.
(4) Ensure that technology is profitable.
(6) Ensure continual improvement in the technology.

The implementation order of the FRs is very important to ensure a successful technology development. The first FR states that a technology strategy must be defined and must be coherent. This ensures that different technologies being developed are coherent with one another, achieving, thus, a common objective in the global strategy of the firm. The second FR states that the technology must be applicable and must satisfy the external customer imperatives. Technologies that do not have commercial applications or do not respond to the external customer needs should not be developed. This doesn't mean that companies shouldn't explore technologies with future applications for future customer needs. However, these technologies should be introduced only when the market is ready for them, which wasn't the case for example for the Newton in the example discussed above. The third objective has to do with reducing the time it takes to develop a technology. As it has been described in CHAPTER 2, this FR is becoming an important and crucial objective in today's environment. The fourth objective has to do with profitability of the technology by ensuring that labor and material resources put in the development of the technology are optimized. The fifth FR ensures that the organization improves its technology development process by learning from mistakes and incorporating new and innovative technology development concepts (such as the Internet and virtual team management) to subsequent projects.

The following figure shows the lower level FRs that have selected to satisfy the overall objective and the associated DPs:

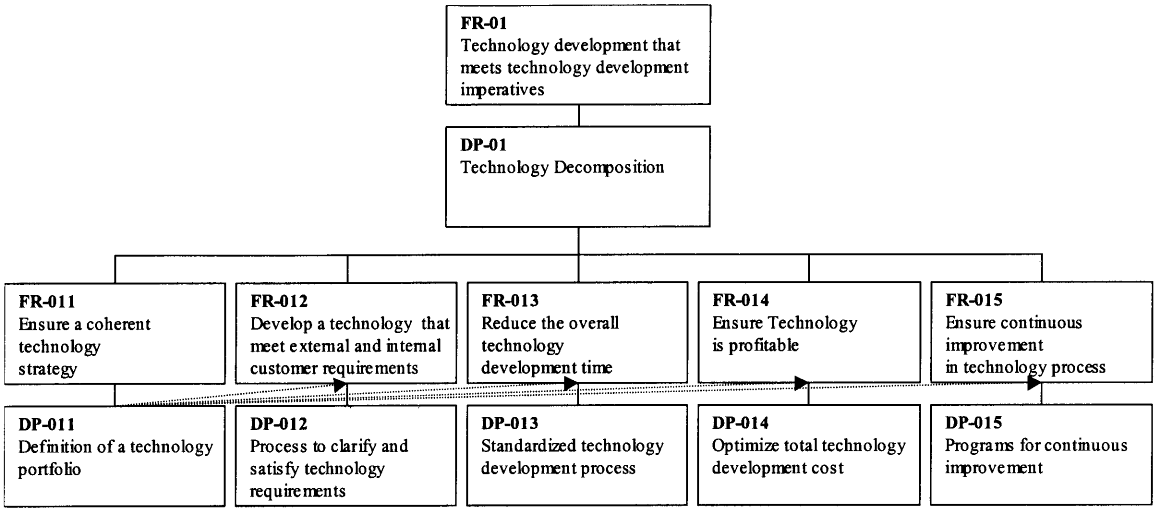

Figure 10: Top-level FR-DP Couples of the Technology Decomposition

3. TECHNOLOGY STRATEGY

As stated above, in order to succeed technologically, a company must have a global technology strategy, where, in addition to meeting customer requirements, technology contributes to the intangibles of the company such as the brand, which is becoming a very important way for differentiation in a highly competitive market. For example, an automaker can use technology to reinforce its luxury image. This is the case for example with Mercedes and the S class model that has been discussed earlier in CHAPTER II. Technology can be used also to build image around a feature. This is the case, for example, of Volvo, where in addition to commoditized technologies that are considered as a must by customers (for example ABS for the brakes system), additional technologies are developed to reinforce a targeted feature (Safety in the case of Volvo). Based on these remarks, the DP for having a coherent technology strategy is defined as DP-001 "Definition of a technology portfolio". Then in order to achieve this objective, the above pair was decomposed further down by simply asking the question, of how can the company define a technology portfolio. Three functional requirements were developed to answer this question: First, there is the need to define technologies and understand them (FR-S1); second, technologies should be built to create a unique image (FR-S2); third, the technologies should be coherent and maximum synergies between them should be extracted (FR-S3). The corresponding DPs of these high-level FRs are illustrated in Figure 11. The following subsections provide a more detailed description of each FR-DP pair and their subsequent decomposition.

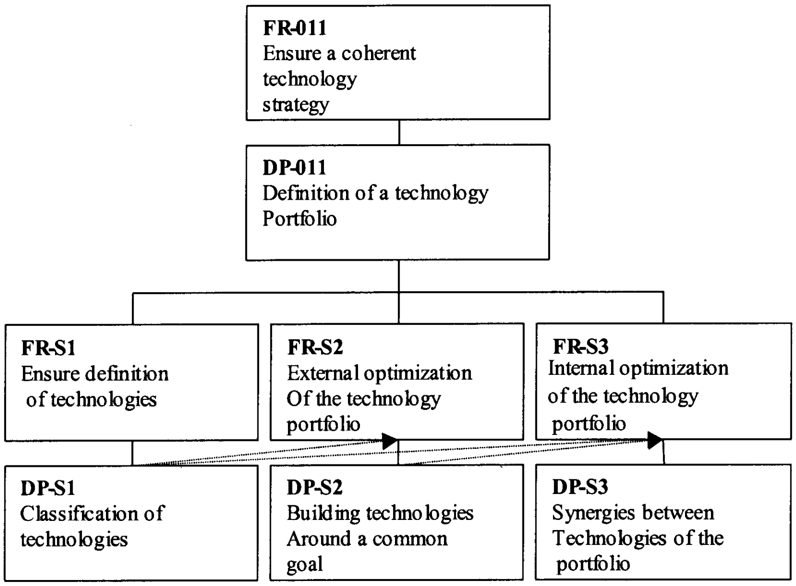

Figure 11: High Level Decomposition of the Coherent Technology Strategy Branch

3.1 Technologies Definition

This branch of the Technology Decomposition describes the importance of understanding the technologies in order to be able to classify them. It is the first objective that needs to be satisfied in order to be able to meet the higher-level functional requirement of ensuring a coherent technology strategy. The corresponding DP-S1: Classification of technologies suggests that the solution to this objective is to first understand the technologies and then understand the implications of these technologies in term of resources (time, financial resources) and in term of competencies. FR-S1 is decomposed into three FRs: FR-S11, FR-S12 and FR-S13. These FRs and their corresponding DPs are illustrated in Figure 12:

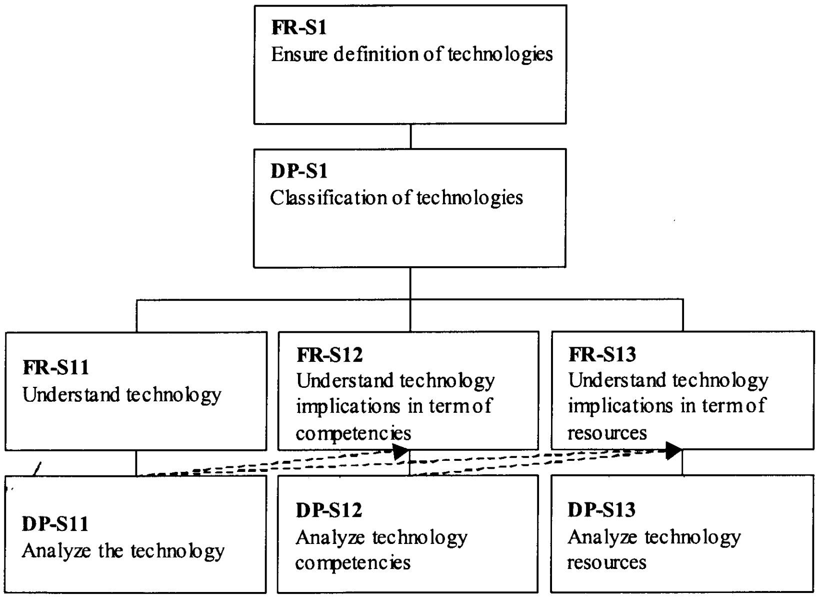

Figure 12: Ensure Definition of Technologies

The first FR, FR-S11: *Understand the technology*, describes how technologies should be assessed and understood. Indeed, technologies are diverse: breakthroughs that imply radical changes in the architecture, the performance, and the price of the products where they are will be integrated. For example the development of flat panel displays technologies led to radical changes in the computer as a product with the emergence of a whole new category of computers: the laptops. On the other spectra of the classification, we can find maintenance technologies that can improve products performance without radical changes. Between those two extremes, we can find technologies that are not necessarily revolutionary, but that add more value to the product than the value added by maintenance technologies. Therefore, as a solution for this FR, DP-S11 is to analyze the technology.

The second FR, FR-S12: *Understand the implications of technologies in term of competencies*, stresses the importance of understanding the requirements in term of competencies that need to be created for technology development. The development of breakthrough technologies requires generally very strong competencies in the field of the technology and involves in many cases fields that are not related to the field of the old technology being replaced. On the other side, maintenance and upgrade technologies require a limited set of competencies and do not require learning knowledge in new fields. Based on this, the DP for this FR is DP-S12: Analyze technology competencies.

The third FR, FR-S13: *Understand the implications of technologies in term of resources*, stresses the importance of understanding the technology requirements in term of resources. Breakthrough technologies generally require much longer development times, much more interactions with manufacturing and marketing and finally require much more resources for successful development. On the other side, upgrade and maintenance technologies require less resources and their development time is generally short. Based on this, the DP for this FR is PD-S13: Analyze technology resources.

3.2 External Optimization of Technology Portfolio

Once the First FR (FR-S1 Ensure definition of technologies) has been achieved and different technologies have been defined and assessed in term of their complexity, and the competencies and resources they require. the technology portfolio must be optimized externally. This can be done by the selection of a set of technologies to be developed. These technologies are a mix between breakthrough competencies and resources consuming technologies on one hand and maintenance resources saving technologies on the other hand. This equilibrium between different kinds of technologies also ensures development risk reduction, as the firsts are riskier and more rewarding than the lasts. However, maintenance technologies have another risk, the risk of not innovating and being a laggard. In order to achieve the objective FR-S2, the technological image that the company should show to its customers should be defined (FR-S21), and then the portfolio of technologies should be optimized around the image (FR-S22). Of course, this optimization is not done arbitrarily, but through market research that reveals how customers see the company, and what is their understanding of the company innovativeness on one hand, and how they should see the company on the other hand. More, internal competencies should be assessed to evaluate the company ability to sustain a given image. The decomposition of this pair FR-DP is shown in the following figure:

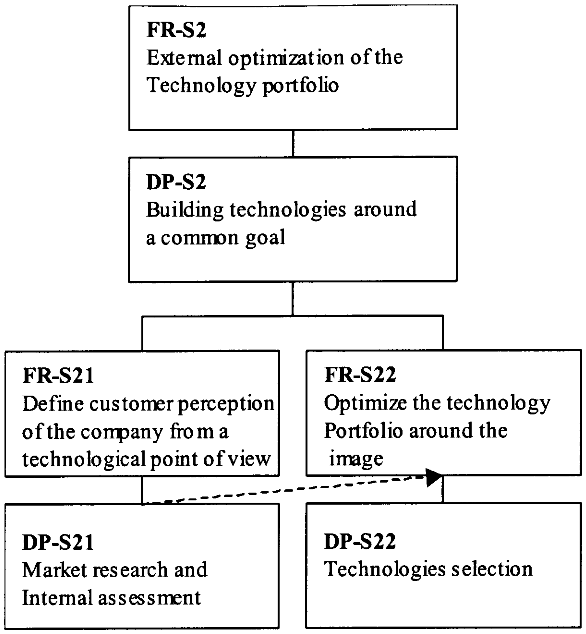

Figure 13: External Optimization of the Technology Portfolio

The first FR, FR-S21 states that *the customer image of the corporation technologically should be defined.* This is generally a strategic decision that is taken by managers. However, if the image they want to give to the company (from a technological point of view) is very different from the current image, this certainly implies a very costly strategy with high risks because the corporation my not have the competencies necessary to execute its strategy. The maneuver margin of managers is therefore not unlimited. In all cases, market research and internal assessment (DP-S21) provide the right solution for defining the image. The best example in this case is perhaps the case of Boeing, which is known for having expertise in civil and military aircrafts. Due to the profitability of the satellite launch business, Boeing spends millions developing its business in this field and moving to this profitable niche. However, all its trials failed miserably because its competencies are in aircraft technologies, not satellites, The satellite launch business is dominated by the European Ariane with more than 50% of the market.

The second FR, FR-S22 states that *the technology portfolio should be optimized around the selected image.* As we have said the technologies that will create the perception should be a mix between breakthrough technologies and maintenance ones. Obviously, the strategy should be revised and assessed regularly as the perception will be certainly developed over a period of several years, a horizon much longer than the horizon of an average technology development time. Based on this, the DP for creating the portfolio around the image is technologies selection (DP-S22).

3.3 Internal Optimization of the Technology Portfolio

Once the external optimization of the technology has been made and the technologies that will be included in the technology portfolio have been defined, the portfolio should be optimized internally. This is the objective of FR-S3: *Internal optimization of the technology portfolio.* The DP for this is DP-S3: Synergies between the portfolio technologies. This pair FR-DP is decomposed into two FRs in a partially coupled design as shown in figure 14. These sub-FRs are: FR-S31: Information sharing and FR-S32: Human resource sharing.

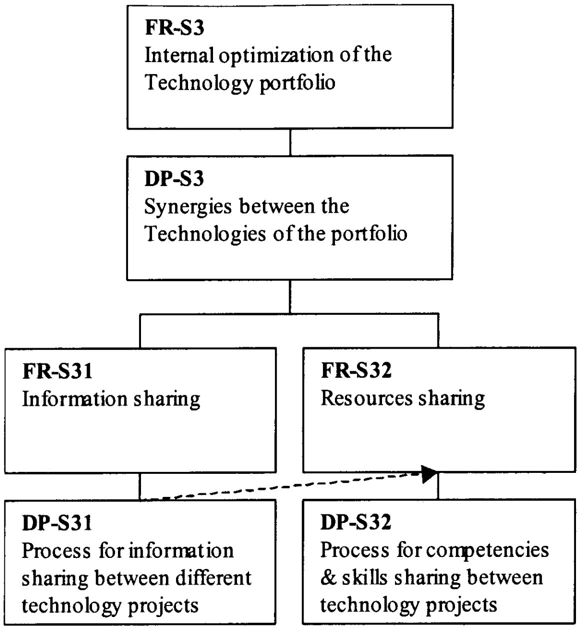

Figure 14: Synergies Between Technologies of the Portfolio

FR-S31 states that information should be shared between technologies if possible. This objective is put here to correct the general believe in some corporations that technology projects cannot be compared because each project is different, this leads to knowledge from one technology project not being applied to others and phenomena like "reinvent the wheel"[11]. The DP for this FR is DP-S31, *a process for information sharing between different technology projects.*

FR-S32 states that human resources should be shared between different technology projects. This objective allows engineers to learn from different technology projects, increasing, thus, their competencies. Furthermore, by working concurrently on multiple technology projects, engineers can bring new out-of-the-box insights to technology development. A process for competencies and skills sharing is the DP for this FR. FR-S32 is affected by DP-S31 because a process for information sharing will affect inevitably the human organization.

4. SATISFY THE CUSTOMER REQUIREMENTS

As stated above, in order to satisfy external and internal customer requirements (*FR-012*), *DP-012 – Process to clarify and satisfy technology requirements* has been created. This FR-DP pair is decomposed into the most important branch of the Technology Decomposition. It is the heart of the technology definition phase. By asking the simple question of "how are the customers requirements satisfied?" this branch was developed. Four functional requirements were developed to answer this question: First, there is the need to understand external customer's requirements (*FR-U1*); second, the technology to be developed must satisfy those requirements (*FR-U2*); third, the manufacturing and integration capabilities of the company must be understood (*FR-U3*); and finally fourth, the technology must meet the manufacturing and integration capabilities of the company (*FR-U4*).

The corresponding DPs of these high-level FRs are illustrated in Figure 15. Also, the following sub-sections provide a more detailed description of each FR-DP pair and their subsequent decomposition.

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[11] Edward Smith, The New Product Development Imperative, HBR 2001

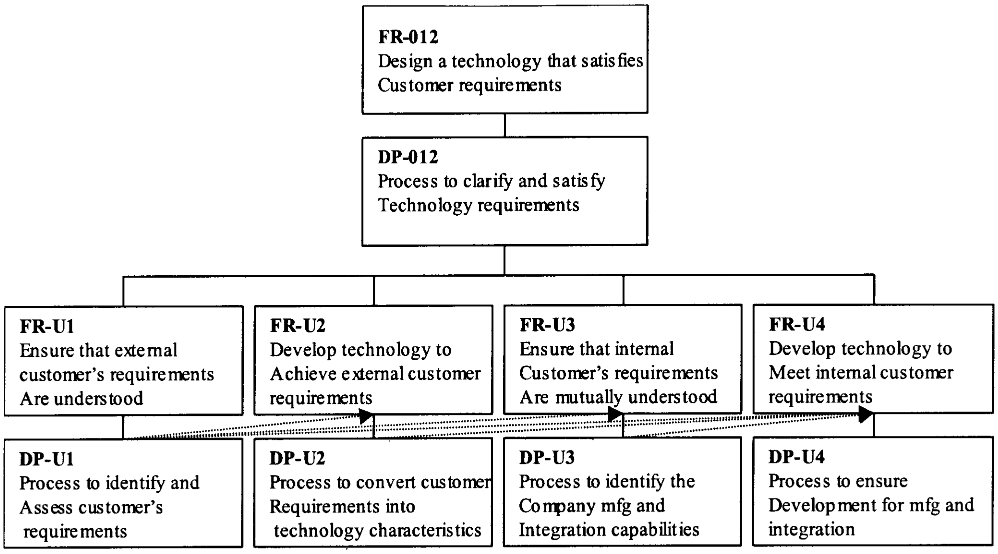


Figure 15: Satisfy Customers Requirements

4.1 Understand External Customer's Requirements

> "If you take care of your customers, everything else will fall into place"
> Lee Iacocca, Founder and Chairman of EV Global Motor Inc.

This branch of the Technology Decomposition describes the importance of understanding the external customer's requirements. It is the first objective that needs to be satisfied in order to be able to meet the higher-level functional requirement of satisfying customer's requirements. The corresponding *DP-U1 – Process to identify and assess customer's requirements* suggests that the solution to this objective is to first identify the external customer's FRs and then to assess these FRs in order to reach full understanding. *FR-U1* is decomposed into two FRs: *FR-U11* and *FR-U12*. These FRs and their corresponding DPs are illustrated in Figure 16.

The first FR, *FR-U11*, describes how to avoid risk associated with having a misunderstanding with the baseline requirements. *FR-U11* requires active participation from the company. *DP-U11 – Study and understand market research* has been assigned as the means to achieving this FR. Basically, this FR-DP pair needs to be met to ensure that the customer and the technology provider (the company) are speaking about the same needs and that the requirements of the technology are well clear.

The second FR, *FR-U12*, recognizes the fact that technology requirements change during the technology development phase, especially in the aerospace and automobile industries where the technology development phase can take decades and the external requirements can change rapidly. Therefore, *FR-U12* identifies the objective of knowing what to do when the customer's requirements change. The means to achieve this objective is summarized as *DP-U12 – Action plan for when customer's requirements change.*

Also, the design matrix in Figure 16 shows an un-coupled design, which implies that each design parameter (DP) is directly linked to its own functional requirement but does not affect the other FRs. The two DPs are independent of each other because understanding the external customer requirements is not related to how an enterprise should respond when those requirements change. *DP-U11* specifies open communication with the external customer to reach full understanding and *DP-U12* describes the need to develop a process to follow when a change in the external customer requirements occurs.

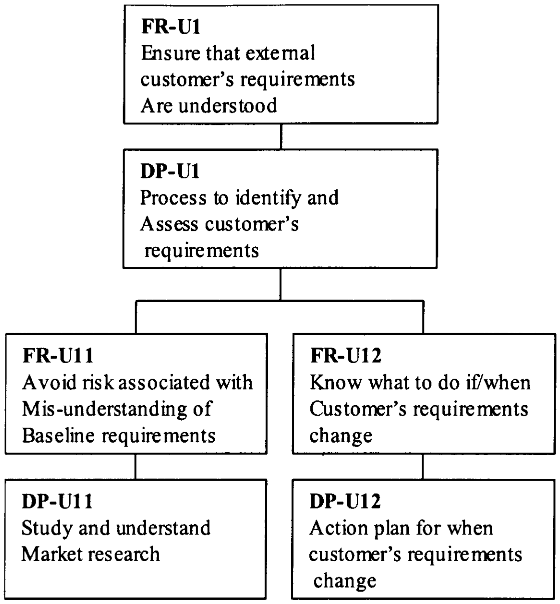


Figure 16: Understand External Customer's Requirements

4.2 Develop Technology to Achieve External Customer Requirements

Once the external customer's requirements have been understood, the technology developer has to define a technology that will achieve those requirements. The DP for this FR is *DP-U2 – Process to convert customer requirements into technology characteristics.* To achieve this FR-DP pair, three FRs are required and can be seen in Figure 17.

The decomposition branch shown in Figure 17 can be viewed as the core of what a technology provider needs to do to allocate tasks to developers, to ensure that resources are available and finally, to create the technology itself. The first functional requirement, *FR-U21*, illustrates the need to allocate the different tasks identified in a statement of work (SOW) to different sub-teams or employees according to their core competencies. Planning and development of an achievable workload to avoid missed deadlines are required. A time-phased statement of work is required so that realistic milestones and deliverables are established for a successful completion of the technology development.

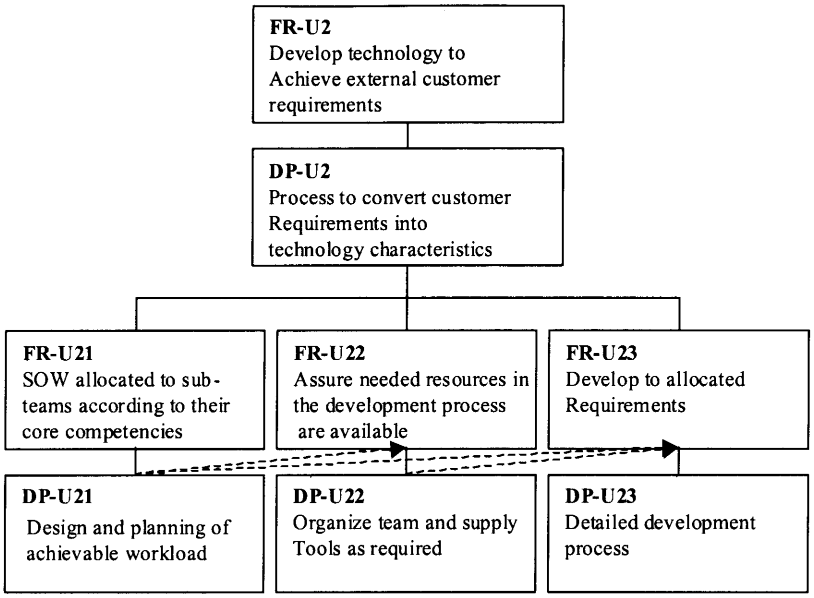


Figure 17: Develop Technology to Achieve External Customer Requirements

Once the tasks and activities of the technology development phase have been defined, assigned and phased over time, a technology manager is responsible for assuring that the required resources are available. This lower-level objective is depicted as *FR-U22* and is described below.

The second lower-level FR, *FR-U22: Assure needed resources in the development process are available*, is a FR for developing a successful technology because it ensures that the necessary resources are available. In this case, there are three types of resources that need to be allocated: 1) a capable organization structure (i.e. management, leaders, and support mechanisms); 2) teams (i.e. experienced workers and new hires); and 3) capable tools and processes. To achieve *FR-U22*, the company must organize sub-teams or integrated technology teams based on the statement of work with capable leadership and team members. In addition, the teams require standard and capable tools that will help them achieve the workload in the statement of work.

The third lower-level functional requirement in Figure 17, *FR-U23: Develop to allocated requirements*, has as a design parameter *DP-U23: Detailed development process*. It is this FR-DP pair that must be achieved to ensure that the technology development is complete. The engineer has already understood the customer requirements, the allocation of tasks with milestones and deliverables has been performed, and the required resources have been made available to the capable teams. This FR specifies that is now time to develop, test and create the technology.

4.3 Ensure that Internal Customer's Requirements Are Understood

In the above section, we have seen through FR-U1 and FR-U2 that external requirements must be understood (FR-U1) and the technology must be designed to take into consideration those requirements and transform them into characteristics and features in the final product (FR-U2). The purpose of this section is to look to the requirements of internal customers' requirements, and in particular, how technology can be manufactured and integrated into a product platform. This FR is put after FR-U2, because in the aerospace and automobile industries technologies are often developed without having a recipient platform for integration. It is only when the development has been completed and technology has been tested that managers start thinking on which product will be the platform for the technology. However, it is necessary for any company to make their development engineers aware of current manufacturing processes and their capabilities. The means to achieve *FR-U31* then becomes *DP-U31: Process to identify and document process capabilities*. This FR-DP pair can be further decomposed into the actual activities of identifying process capabilities, organizing, and making these process capabilities easily accessible to the development engineer. Although this FR-DP

pair is not decomposed further, a lower-level DP to this FR could be an easily accessible and web-enabled process capability database that is constantly being updated.
The other low level FR designed to make FR-U3 possible, looks to the mutual understanding between the other internal customers of the technology (product platform teams) and technology development teams. FR-U32 states the understanding of platforms capabilities and constraints, and try to reduce and mitigates the risk of rework and changes in order to adapt technology to product platforms. The DP for this FR is DP-U32: *Process to identify platform capabilities and constraints.*

Figure 18 illustrates where those pairs of FR-DP pair lies within the Technology Decomposition.

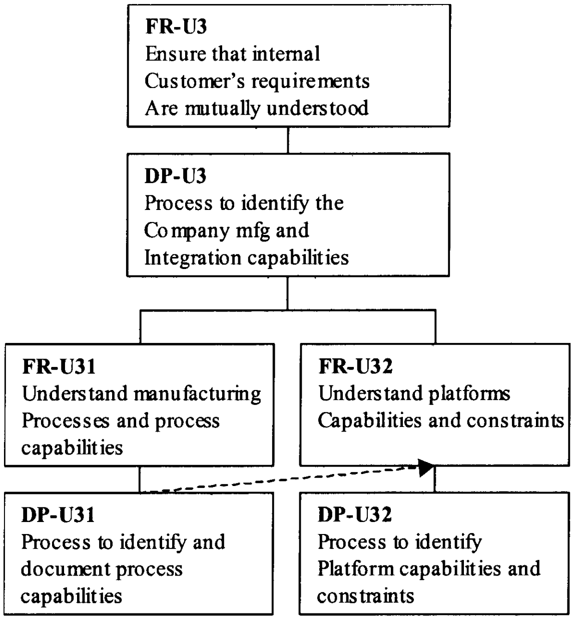


Figure 18: Understand Manufacturing Processes and Process Capabilities

4.4 Develop Technology to Meet Internal Customer Requirements

Once the requirements of internal customers have been mutually clarified and understood, the next step is satisfy the internal requirements in term of manufacturability and integration.

Figure 19 shows the decomposition of *FR-U4* into three FRs, starting with *FR-U41: Optimize assembly plan,* which looks into the assembly process of the technology components and the process or plan that will be developed to optimize the assembly. The second lower-level FR, *FR-U42: Specify the best components and materials*, looks to the "make or buy" process for the selection of components and materials. Finally, the third FR, FR-U43 looks at the optimization of the technology integration in the final products.

Focusing on the first lower-level functional requirement, *FR-U41*, its design parameter describes the application of optimum assembly capabilities to optimize the assembly plan. This FR is achieved by understanding the various assembly process candidates that can be used for the component or part being created. The development engineer is responsible for studying new assembly research to add to the various possible assembly methods. Once the various possible assembly methods are well understood, the development engineer should conduct trade studies and development testing and attempts to develop the component or part to conform to the best assembly process.

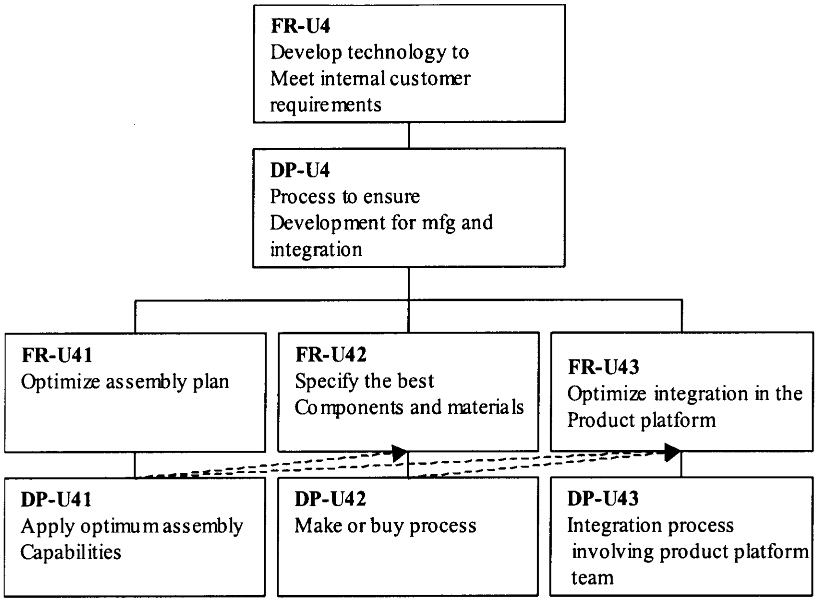


Figure 19: Optimize Design for Mfg. Processes and within Process Capabilities

Finally, the development engineer must validate the assembly process through actual assembly testing before providing the design and assembly process to the manufacturing engineer.

The second lower-level functional requirement is *FR-U42: Specify the best components and materials* is achieved with *DP-U42: Make or buy process*, which specifies that an efficient "make or buy" process is needed in a corporation in order to be able to specify the best components and materials for the technology being developed. This FR-DP pair can be decomposed even further to show more detail on how to achieve a world-class "make or buy" process. The first FR could be to have a working knowledge of the providers/suppliers capability by maintaining databases of suppliers and their capability. Also, when a "buy" decision is reached, the development engineer should attempt to utilize "off-the-shelf" parts for the technological system.

The last lower-level functional requirement of this branch decomposition is *FR-U43: Optimize integration in the product platform.* This FR can be achieved by designing a process for cross-functional teams, and active involvement of platform design teams along the technology development value stream. On the other hand, engineers from technology development can be also involved in the platform development. The DP that has been selected for this FR is DP-U43*: Integration process involving product platform team.* This point will be further detailed in the next chapters, and in particular in the Ford Motor Company Case Study.

5. REDUCE THE OVERALL TECHNOLOGY DEVELOPMENT TIME

The third high-level objective for successful technology development is to reduce the amount of time it takes to conceive and create a technology. This FR is key to the success of the technology, especially in the aerospace and the automobile industries where the development of a new avionic technology or a handling control system may take years or even decades. There are many reasons why the development time of an aerospace or an automobile technology takes so much time; however, the main reason is that airplanes and cars are very complex products with thousands of systems interacting together. Nevertheless, there is a lot of room for improvement in a technology development process to reduce the time it takes to create a technology, starting from reduction of waiting time, traveling distances, re-iterations in the design and basically any form of non-value adding tasks and activities.

The high-level design parameter that will achieve this FR is *DP-013: Standardized Technology Development Process.* What this DP intends to define is that by having standardized processes in the development phase, the customer need date will be met, because the development time is standard, and therefore the time taken to develop a technology should be visible to the end user. Also, a standardized process ensures that improvement can be made, minimizing, thus, non-value added tasks and activities by streamlining the process and eliminating waiting time and traveling distances. Finally, a standardized design process can help minimize the reiterations in the development process and hence reduce the overall time it takes to develop the technology. Figure 20 shows this high-level FR-DP pair and its subsequent decomposition into three FR-DP pairs.

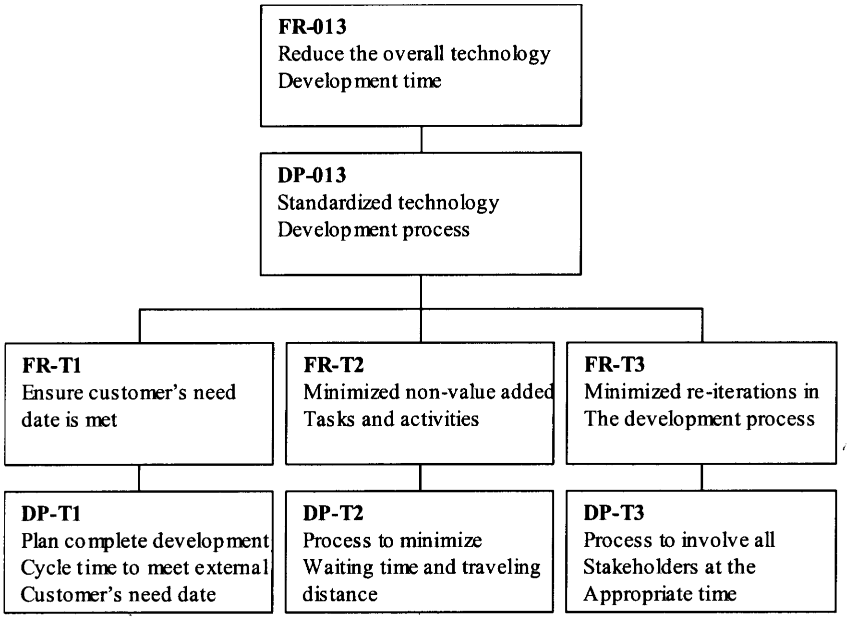


Figure 20: Schedule, Reduce Overall Technology Development Time

The top-level functional requirement in Figure 20 is decomposed into three FR-DP pairs. The first functional requirement, *FR-T1*, states that the customer need's date needs to be met. This FR is closely tied with satisfying the external and internal customers' requirements because the due date is usually also a customer requirement.

The second functional requirement or *FR-T2* describes the need to minimize as much as possible non-value added tasks and activities. These tasks and activities do not add value to the technological system. They do not change the performance of the technology and are usually divided into two groups: waiting and traveling distances.

Finally, the third functional requirement or *FR-T3* tries to minimize the reiterations in the design process. These reiterations cause re-work and convert the originally value-added work into non-value added work. The following sub-sections will discuss in detail *FR-T1*, *FR-T2*, and *FR-T3*.

5.1 Ensure Customer's Target Date is Met

As mentioned above, the first high-level functional requirement in the Cycle time reduction branch deals with the customer requirement of due date. The objective is to ensure that the customer's need date is achieved. This ensures not only the satisfaction of the customer but gives the company a competitive edge as well. By timely introduction of the technology, the company can overrun competitors who witnessed delays in introducing similar technologies. The means to achieve this objective is described as *DP-T1: Plan complete development cycle time to meet internal and external customer's need date.* This FR-DP pair becomes a matter of project management and making sure that the entire development cycle is planned including unexpected tasks, activities and delays. In order to do so, this FR-DP pair is decomposed into *FR-T11: Identify the process time limitations and* *constraints* and *FR-T12: Ensure all processes and tasks are done before the customers need date.* These processes include preparation, prototyping, testing, and integration…

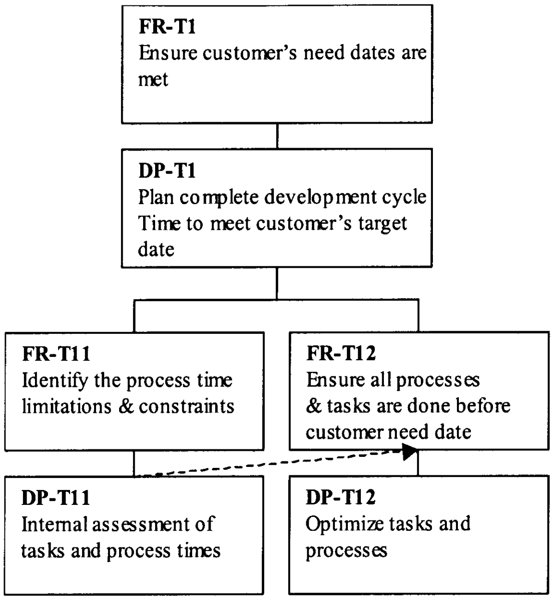


Figure 21: Ensure Customer's Need Date is Met

5.2. Minimize Non-Value Added Tasks and Activities

Non-value added tasks do not change the performance of a technology (by performance we mean all what can add value to the customer). Non-value added tasks could be divided into two different types: waiting time and unnecessary traveling. Also, unnecessary inventory or designs being done at an early stage become non-value added because the requirement might change and the design must be consequently changed. Based on this, the high-level functional requirement, *FR-T2*, has been decomposed into three lower-level functional requirements that can be seen in Figure 22.

DP-T21: Implement just-in-time work schedule is the DP that satisfies the objective *FR-T21: Minimize unnecessary inventory (designs are not done too early).* This FR-DP pair has been included as part of the schedule branch to aid in having standardized design processes by implementing just-in-time work schedules. This DP is similar to the just-in-time concept used in the Toyota Production System (TPS), but instead of physical parts, the product is information and data that are developed during the technology development process. The development engineer should have a balanced work-loop in such a way that there is no inventory accumulating when he/she is working on another technology, yet when the design is complete the development engineer will have another design to work on.

A development engineer waiting to technology data is the opposite of having inventory accumulating. This event is described in the second lower-level functional requirement or *FR-T22: Minimized waiting time (designs are not done too late)* and it is paired with the design parameter *DP-T22: Have material and resources available when needed,* which will achieve such objective. It is crucial to note that not only does a design need to be available to the development engineers but necessary resources so that the development engineer can begin working on the design immediately are also needed. This objective can be decomposed further to illustrate that resources need to be scheduled so that they're available when needed. Also, it is at this point where standardized tools (software, hardware, etc.) should be implemented to minimize the time spent on converting data from one system to another. Finally, a lower-level objective of minimizing waiting time due to lack of training can be satisfied by supplying standardized training for all team members.

The third lower-level functional requirement of this branch is *FR-T23: Minimize traveling distance.* This FR is achieved with *DP-T23: Actual, dynamic and/or virtual collocation*, which specifies that a variety of physical and non-physical collocations for the various team members of a development team is needed in a corporation to minimize the distance the team members must walk. If the interaction among team members is high, then an actual collocation is advised. If the interaction is temporary, then a dynamic collocation is a better arrangement. Finally, a virtual collocation is recommended if the interaction is limited. With the advances in Internet and telecommunications technologies, even if the interactions are frequent, virtual collocations will begin to make more business sense.

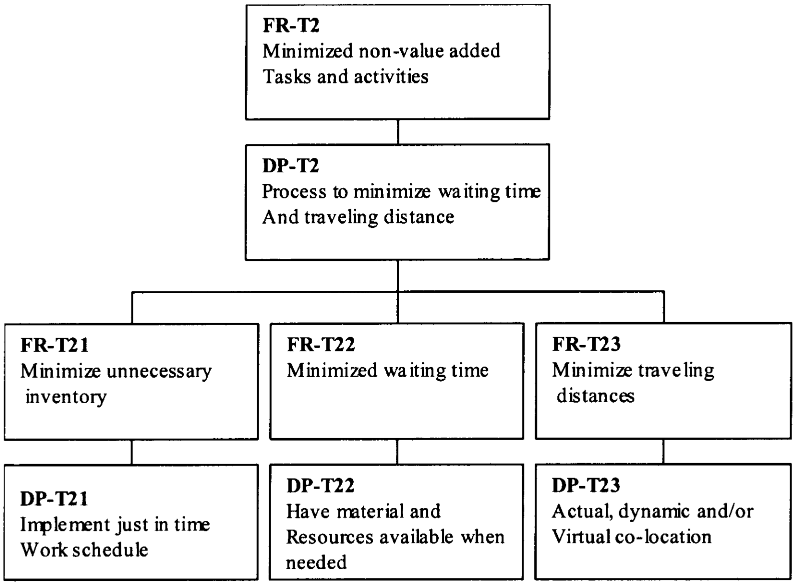


Figure 22: Minimize Non-Value Added Tasks and Activities

5.3. Minimize Reiterations in the Development Process

One of the main reasons why *FR-T3: Minimize reiterations in the development process* was included in the Technology Decomposition was to make the case against companies that change the specifications for a new technology so often in the development phase because of bad market research or because of delays in the overall development process that technology is already outdated as soon as it released. This obliges rework and redevelopment to adopt the technology and make it more coherent to the new market requirements.

This objective or FR was then expanded to include an even more important objective: communication among stakeholders to make the decisions and orientations clear as soon as possible. This new objective of increased communication must be seen as an enterprise objective and should be considered an objective that has a significant impact on the time it takes to develop a technology. Another FR that was included in this branch was *FR-T33: Minimize the time it takes to authorize a good suggestion.*

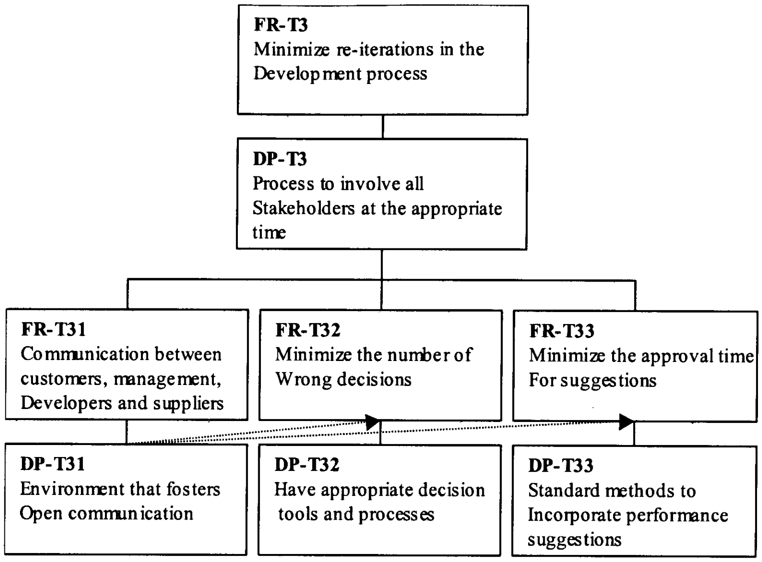


Figure 23: Minimize Re-iterations in the Development Process

The first lower-level functional requirement, *FR-T31: Improve communication among customers, management, team members and suppliers* looks at the entire supply chain, from the suppliers to the end user. The design parameter developed to achieve this objective is *DP-T31: Environment that fosters open communication*. More specifically, in order to improve communication with the customer, the ideal solution is to have meetings between technology developers and marketers who are supposed to be in touch with customers. To improve communication among team members and with management, team meetings and collocations should be arranged as a design parameter. Finally, to improve communication with the suppliers, it is ideal to have a representative of the enterprise at the suppliers' location and vice versa. In addition, the enterprise needs to involve the supplier at an early stage in the development process.

The second lower-level functional requirement, *FR-T32: Minimize the number of wrong decisions* is meant to ensure that wrong decisions that oblige rework should be avoided through insightful tools and expert systems for decision making. Statistics and risk management provide good tools for that. In addition, processes for decision assessment and risk mitigation should be created and implemented (*DP-T32: Have appropriate decision tools and processes.*)

The third lower-level objective is tied to continuous improvement. A company cannot be blind to suggestions that can increase the performance of the technology it is developing, especially if the additional benefit is important in comparison with the cost of implementing the suggestion. This objective deals with the time it takes to implement a suggestion that will make a technology more successful. As a design parameter, *DP-T33: Standard methods to incorporate performance suggestions,* was selected to achieve *FR-T33: Minimize approval time for suggestions.*

6. ENSURE TECHNOLOGY IS PROFITABLE

The three previous branches of the Decomposition, Strategy Imperatives, External and Internal Users Imperatives, and Time Imperatives, dealt with costs in a unique way. Although the objectives were geared towards avoiding strategic mistakes, satisfying external and internal customer requirements, and developing technologies in the minimum amount of time, all these FRs translate to capital. If strategic objectives from technology are missed, the company will be obliged through costly acquisitions and alliances to correct its mistakes and acquire the technology from competitors. If customer requirements are not satisfied, then the customer will not be willing to pay enough for the technology. If the technology itself is not producible, then costs will be incurred in the form of re-work, scrap, defects, etc. Finally, the longer the time it takes to develop a technology, the more costs will be incurred in the form of direct and indirect labor. This fourth branch looks at the costs that were not taken into consideration by the first three branches. Specifically it looks into how the budget is disbursed for both direct and indirect labor.

The top-level functional requirement *FR-014: Ensure the technology is profitable* is decomposed into two FRs: *FR-C1: Optimize direct technology development cost* and *FR-C2: Minimize the indirect technology development cost.* It is necessary to be aware that the word "optimize" was used for direct technology development cost because if cost is minimized, there is a higher probability that the best technology specifications might not be achieved due to the fact that developers will attempt to minimize costs at every respect compromising the performance of the technology. However, the word "minimize" was used for the indirect technology development cost because this is considered non-value added work and therefore does not change the performance of the technology.

Figure 24 shows the decomposition of this high-level FR. The partially coupled design matrix that describes the affect that *DP-C1* should be noticed*: Processes for schedule and financial information and monitoring* has on *FR-C2.* Also, the chosen design parameter for *FR-C2* is *DP-C2: Process to eliminate non-value adding tasks.*

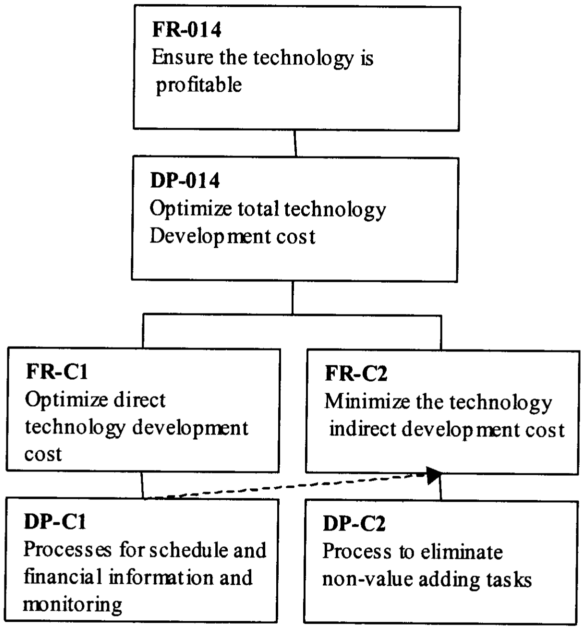


Figure 24: Ensure Technology is Profitable

The following sub-sections describe in more detail the sub-levels of the above pair FR-DP decomposition.

6.1. Optimize Direct Technology Development Cost

Optimizing the direct cost of the technology development is a high priority in many industries, especially in industries where this cost accounts for a high percentage of the total cost of the product that will incorporate the technology such the computer industry. In the automobile industry, this is not the case, since the main cost comes from production and material, however, the development of a new technology such as airbags or control systems is generally estimated in some hundred millions dollars. The high-level objective then becomes *FR-C1: Optimize Technology direct development cost* and the design parameter to achieve this objective is *DP-C1: Processes for schedule and financial information and monitoring.*

This high-level objective can be decomposed into three lower-level functional requirements, starting with *FR-C11: Optimize budget for planned development tasks*, then *FR-C12: Appropriate funding at* *the various stages of development* and finally *FR-C13: Ensure cost effectiveness is being achieved.* These functional requirements and their respective design parameters are illustrated in Figure 25. This figure also contains a partially coupled design matrix, which implies that the design parameters affect the sub-sequent functional requirements.

The objective of the first lower-level functional requirement, *FR-C11,* is to look at the planned development tasks and allocate the appropriate funding to every task. The means to achieving this objective is described as *DP-C11: Procedure to appropriately allocate budget for planned development tasks.* This FR-DP pair deals with the issue of waste created from over budgeting or under budgeting different tasks. One of the main reasons for this is a poor estimating process and unforeseen tasks and activities that were not accounted for. The logic behind *DP-C11* is to implement a good cost and time estimating process for every development task and also to include some management reserve funds for tasks and activities that are unforeseen.

Once the objective of allocating the budget for the planned development tasks has been accomplished, the appropriate funding has to be distributed at the right time. This functional requirement seen as *FR-C12* is achieved with the design parameter *DP-C12: Distributed budget against planned development tasks per schedule.* This FR-DP pair looks at the distribution of funds to the various development teams during the various stages of the technology development. The distribution should be done based on the schedule and if the schedule changes so should the distribution of funds.

The FR-DP pair *FR-C13,* ensures that cost effectiveness is being achieved by means of *DP-C13: Conduct regular cost reviews and modify business plan to adapt to any changes.* This FR-DP pair continuously measures the ongoing performance of the teams against the planned (and budgeted) work. It provides early visibility, and alerts management, of any cost overrun condition. It therefore provides the opportunity for timely corrective action, and precludes unnoticed cost overruns.

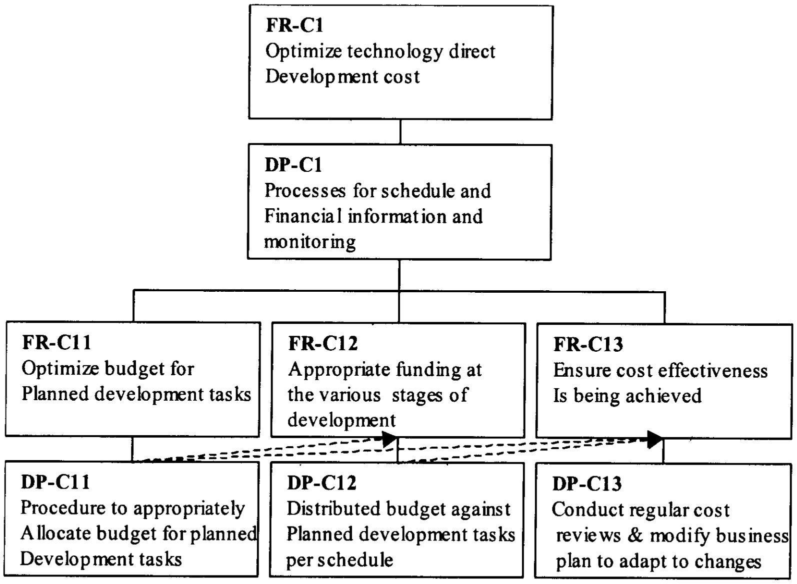


Figure 25: Optimized Direct Technology Development Cost

The above decomposition looked at direct technology development costs only. The following sub-section describes the objective of making sure the technology is profitable by minimizing the technology indirect development cost.

6.2. Minimize the Technology Indirect Development Cost

This decomposition of the cost reduction branch deals with the indirect costs created by indirect labor (tasks and activities). These indirect costs are considered non-value added since these costs do not change the performance of the final technology. However they are necessary tasks and cannot be eliminated radically. In fact, their cost should be minimized. There are two different types of technology indirect development costs that can be minimized. The first type is the costs associated with indirect tasks and the second type is costs associated with overhead costs such as supplies, etc.

This functional requirement, *FR-C2: Minimize the technology indirect development cost*, is achieved by implementing its design parameter or *DP-C2: Process to eliminate non-value adding tasks.*

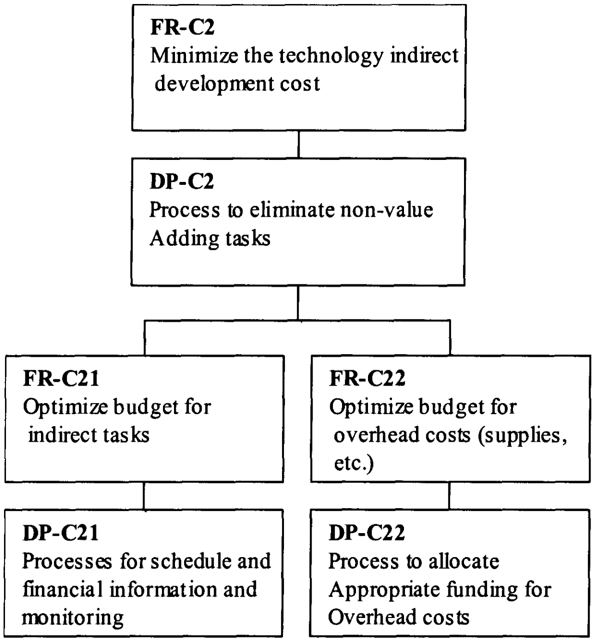


Figure 26: Minimize the Indirect Technology Development Cost

As mentioned above, the first type of indirect development cost is represented by the first lower-level functional requirement, or *FR-C21: Optimize budget for indirect tasks.* This FR states the need to optimize the budget for indirect tasks by streamlining tasks of the development process that relate to indirect labor. For example, the purchasing department is considered an indirect task and should, therefore, be streamlined so that only the required personnel are in charge of the purchasing.

The second lower-level functional requirement, *FR-C22: Optimize budget for overhead costs (supplies, etc.)* is achieved through *DP-C22: Process to allocate appropriate funding for overhead costs.* This FR-DP pair attacks the misuse of supplies and overhead tools. The design parameter intends to tell the user to implement a system or process that allocates appropriate funding or even allocate the appropriate supplies to the various departments that require these supplies.

7. CONTINUOUS IMPROVEMENT

The fifth and last branch of the Technology Decomposition deals with continuous improvement, a crucial objective in order for the organization to stay competitive and survive the challenges of rapid technological changes. New processes and work methods, along with new telecommunication tools are taking place, in particular the emergence of Internet and it changing the way organizations do business. These tools should be integrated and assimilated in the technology development process to continue achieving the technology objectives and improve performance indicators. The DP for the continuous improvement FR is the DP-015: Programs for Continuous Improvement.

The top level functional requirement of this branch is decomposed into two functional requirements. The design is partially coupled and a representation of the branch decomposition can be found in the following figure:

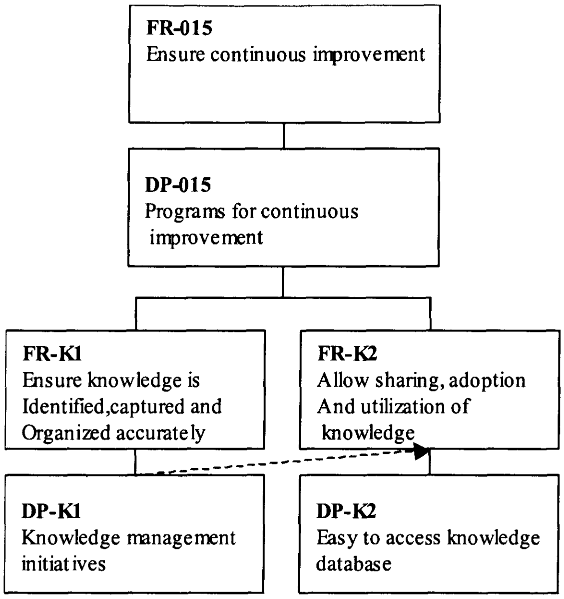


Figure 27: Decomposition of the Continuous Improvement Branch

7.1. Ensure Knowledge is Identified, Captured, and Organized Accurately

The reason for this functional requirement is to have a working database of processes, solutions and any other type of useful information that could help the user to make a better technology. However, this database must be controlled and overseen with critical discipline. The users should be clear on what is "knowledge" and what processes are in place to capture that knowledge and organize it accurately. The design parameter assigned to this functional requirement is *DP-K1: Knowledge Management initiatives.*

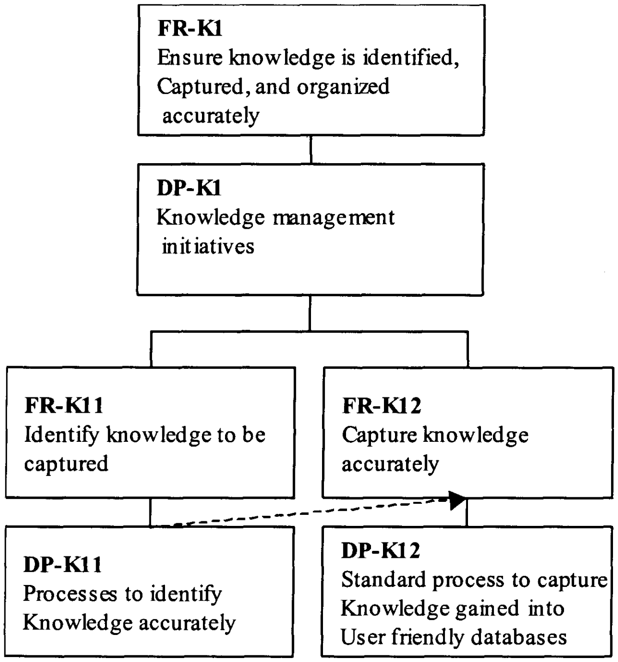


Figure 28: Ensure Knowledge is Identified, Captured, and Organized Accurately

The first lower-level functional requirement, *FR-K11: Identify knowledge to be captured* attempts to identify what knowledge is considered useful and worthy to be captured. In other words, there's no need to capture knowledge that is not useful and will not have a useful application in the future. The design parameter assigned to this functional requirement is *DP-K11: Process to identify knowledge accurately.*

The second lower level functional requirement of the continuous improvement branch looks into capturing the useful information and knowledge. Once the knowledge has been identified then *FR-K11* has been satisfied and now *FR-K12: Capture knowledge accurately* must be satisfied. Here the design parameter is *DP-K12: Standard process to capture knowledge gained into user friendly database.* This DP looks into the knowledge and states that it has to be captured in an easy to use and organized database.

It is critical to note that this knowledge is useless unless the stakeholders in the technology development process utilize it to improve their current processes. The next FR-DP pair will describe both the objective and the means of achieving utilization of this useful knowledge.

7.2. Allow Sharing, Adoption and Utilization of Knowledge

In the previous sub-section, a description of how to identify and capture useful knowledge was made. In this sub-section, the sharing, adoption and utilization of this knowledge is discussed. The objective is described in *FR-K2: Allow sharing, adoption and utilization of knowledge* and the means to achieve this objective is *DP-K2: Easy to access knowledge databases.* This FR-DP along with its decomposition can be seen in Figure 29. In this figure, there's also a partially coupled design matrix, which implies that the first lower-level design parameter has an indirect affect on the second lower-level functional requirement.

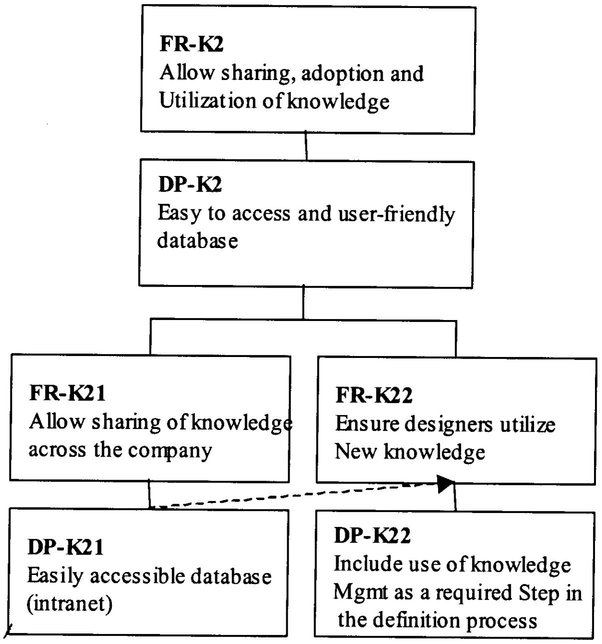


Figure 29: Allow Sharing, Adoption and Utilization of Knowledge

The first lower-level functional requirement of this decomposition, *FR-K21: Allow sharing of knowledge across the company* describes the need to have an open communication tool across the corporation so that development engineers can share their tools with manufacturing engineers, marketers and managers and vice-versa. The design parameter that intends to accomplish this objective is *DP-K21: Easily accessible database (intranet).* This design parameter defines that the database has to be accessible and easy-to-use for all the employees of the enterprise. This will allow for easy sharing of information.

The second lower-level functional requirement looks at the utilization of this information. It is not sufficient to identify, capture and share the useful information throughout the corporation, there's also the need to utilize this information in a productive manner that will make the technology more successful, by either adding a functionality that the end-user is willing to pay for, making the technology more easily producible, reducing the time to create a design, or reducing any indirect or direct labor to the technology development process.

8. CONCLUSION

The originality of the Technology Decomposition that has been developed in this chapter stems from the possibility of applying it to virtually all type of industries. Aerospace and automobile industries are two examples, but none of the FR-DP pairs are specific to one of these industries. The decomposition has a higher-level objective FR-01: "Technology development that meets technology development imperatives" which is the objective of any technological organization that doesn't only want to survive the technology challenges, but succeed as well.

It must be noted that for any technology development strategy to be successful, there are five main objectives to be satisfied:

(1) Ensure coherent technology strategy.
(2) Design an applicable technology that satisfies the external customer imperatives.
(3) Reduce the overall technology development time.
(4) Ensure that technology is profitable
(5) Ensure continual improvement in the technology process.

The main point to emphasize when considering a decomposition such the one made in this chapter, is the organic links between the objectives and the means designed to achieve them. This understanding of links creates a mental model that allows technology development managers to:

(1) Improve technology development process having high-level objectives in mind and constantly looking for solutions to achieve them.

(2) Design the organization and the responsibilities so that the higher objectives are met. The lead manager will have the top-level objectives responsibilities and from there on, the various FR-DP pairs can be assigned to teams in the organization. This provides a guide for the division of responsibilities making, thus, the organization more effective.

(3) Create opportunities for improvement, since the process for technology development is standard and being understood by every member of the organization, areas of weakness appear automatically and improvement can be made.

A full design matrix for the entire Technology Management Decomposition that describes the interactions between the DPs and the FRs is illustrated in the appendix.

CHAPTER 5: MAPPING OF LEAN ENGINEERING FRAMEWORK AND TECHNOLOGY DECOMPOSITION

1. INTRODUCTION

In the previous chapter, we have constructed, using the axiomatic design methodology, a Technology Decomposition that links organically the high level objectives of technology management and the organizational and operational solutions designed to achieve them. In this chapter, we will present a framework that has been developed within the Lean Aerospace Initiative at the Massachusetts Institute of Technology to approach Lean Engineering. Although the framework has been originally developed for product development, we found it applicable in the case of technology development with some adaptations. After all, like in the case of product design, technology development is the activity of transforming data and information using engineering skills.

Then, based on the previous chapter decomposition, a mapping between the Lean Engineering Framework and the Technology Decomposition is made. The objective is to assess if Lean Concepts, such they were developed in the particular case of engineering lead effectively to the achievement of the corporate technology strategy (the higher Functional Requirement of the Decomposition.)

2. THE LEAN ENGINEERING FRAMEWORK

The Lean Engineering Framework was developed by Professor Hugh McManus at the Massachusetts Institute of Technology within the Product Development Focus Team of The Lean Aerospace Initiative. The Lean Engineering Framework seeks to apply the Lean principles that were first developed in the field of manufacturing to the field of engineering.

In the first chapter of the thesis, we have summarily presented the origins of lean concepts and how they have evolved over a period of several decades, first in Japan, then in the United States with the publication of "The machine that changed the world" in 1991. However, even if Lean Principles have originated from manufacturing situations, they are applicable to virtually all processes in order to make improvement and pursue perfection. As detailed by Womack and Jones, Lean Thinking can be summarized in the following steps:
(1) Precisely specify value by specific product
(2) Identify the value stream for each product
(3) Make value flow without interruptions
(4) Let the customer pull value from the producer
(5) Purse perfection

These steps, which do not depend on the underlying process, and can be applied either in the case of a physical process or an information transformation process, can be summarized in three main points:
(a) Understanding the underlying process by identifying what is value, how it is added to the product, what are the steps that add most of the value? What are the steps that do not add value?
(b) Eliminating waste by eliminating the steps that do not add value to the underlying process and optimizing the others, creating thus, a seamless flow of value pulled by the customer.
(c) Continuous Improvement by constantly looking for new opportunities to add value to the process and searching for new configurations that allow a better optimization of the process, pursuing thus, perfection. Perfeotion in this case, means delivering what the customer wants with the perfect quality, immediately, at no cost.

The Lean Engineering Framework adapts the Lean principles summarized above, to engineering cases. Although its use has been limited so far to successfully designing new products, the attempt here is to apply the framework to new technology development and to assess if it can provide a road map for successful technology development and integration.

The Lean Engineering Framework (applied to technology development) consists of the following six steps that will be detailed further more above:

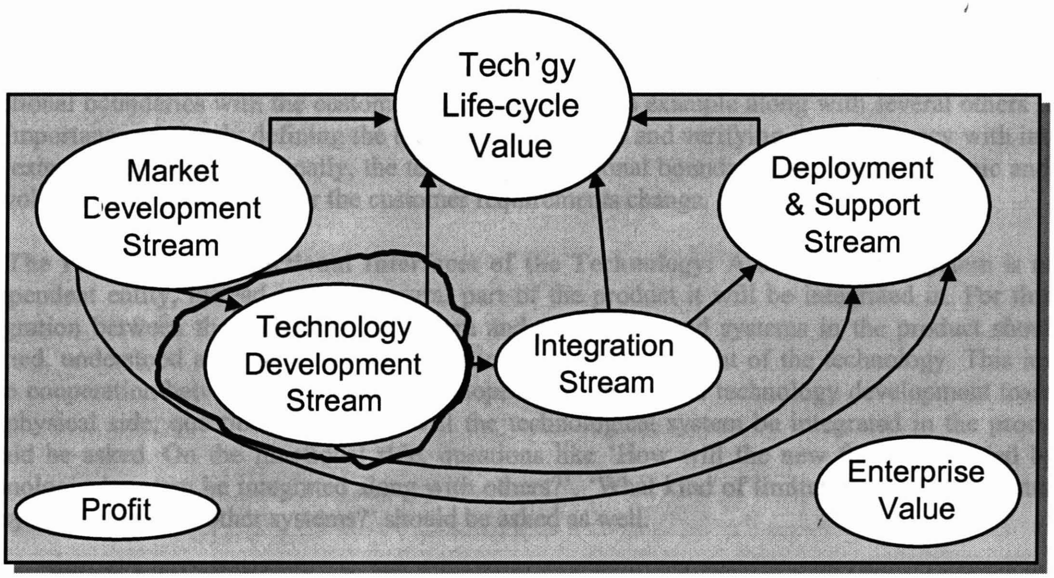
1. Start with the big picture
2. Define the technology and its boundaries and interfaces
3. Define value in the above context
4. Map information streams
5. Identify and eliminate waste
6. Enable flow and look for opportunities for radical change.

2.1. STEP 1: Start with the Big Picture

This is the first step in improvement process: understanding what is the place of technology development in the entire technology life cycle. In reality, technology development can be seen embedded in two ways:

(1) Embedded in the technology lifetime: technology development is only one step in the technology life cycle. Among other steps are the technology integration in the product and the deployment of the technology.

(2) Embedded in the Supply chain: technology development can be viewed as a supply to manufacturing with the necessary information and knowledge to produce systems that add value to the products sold to the customer. Therefore, technology delivers value to the final customer indirectly; technological systems must be integrated in the product, manufactured, upgraded before creating value to the customer.



Source: LAI, PDF Team

Figure 30: Overview of the Place of Technology Development

2.2.a. STEP 2(a): Define the Technological System

In order to implement Lean, the technological system (the technology) under development must be clearly defined. However, since at the time of development, the final form of the technology is unknown, the definition of the technological system can only be descriptive. In any case, it is very important to understand the following elements about the technology:

(1) The nature of Technology: As it has been presented in the previous chapter, understanding the nature of technological systems is crucial to their success. Indeed, By categorizing technology projects by type, the company begins building a framework, which facilitates the recognition of patterns and their systematic analysis for learning.[12] This in turn allows the company to allocate the right resources and the right target time for the development of the technology. More, understanding the technology allows the company to understand its requirements in term of skills and competencies and adequately supply its teams with these ones (either by training and education or through new hires).

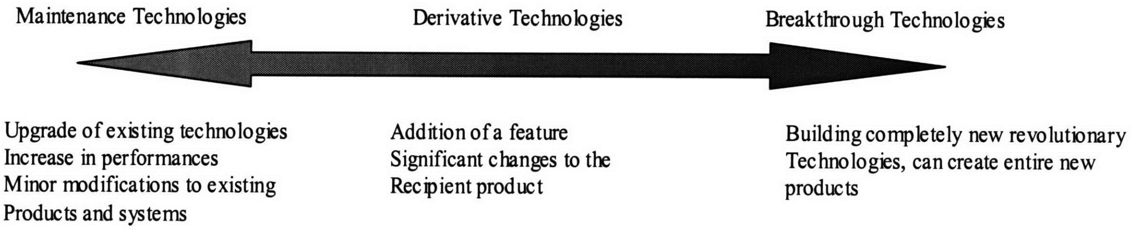


Figure 31: Understanding the Nature of Technologies[13]

(2) The Physical Boundaries: Given the limitations and constraints of the products that will incorporate the technology, it is crucial to define the physical boundaries of the technological system, for example, hydrogen powered cells were not introduced in cars because their size consumes up to half of the car size. In addition, ignoring the physical limitations around the technological system results inevitably into a redesign, either the redesign of the product to adapt to the physics of the technological system or the redesign of this last to adopt to the product physics.

(3) The Functional Boundaries: In the example of APPLE's NEWTON that was discussed in an earlier chapter, one of the main reasons for the failure of the product, was the inadequacy of the functional boundaries with the customer specifications. This example along with several others shows the importance of clearly defining the technology functions and verifying their adequacy with internal and external requirements. Finally, the technology functional boundaries should be dynamic and able to evolve with time or whenever the customer requirements change.

(4) The Physical and Functional Interfaces of the Technology: A technological system is not an independent entity, instead it is an integral part of the product it will be integrated in. For this, the integration between the technological system and other parts and systems in the product should be defined, understood and taken into consideration in the development of the technology. This implies close cooperation between the platform development team and the technology development team. On the physical side, questions like 'How will the technological system be integrated in the product?', should be asked. On the functional side, questions like 'How will the new functions added by the technological system be integrated along with others?', 'What kind of limitations and constraints will the system impose on other systems?' should be asked as well.

2.2.b. STEP 2(b): Define the Process

Once the Technology has been defined in the previous step in term of its physical and functional boundaries and interfaces with other systems defined; the next step is to define the processes and the activities that will be assessed for improvement. The main issue is that the technology development is not a standalone process. On the contrary, it is very integrated with virtually all functions in the company. Certainly more than in the case of product development since technology is not a standalone product but needs an integration platform to be commercialized. However, even with this level of integration, the study area can be limited to a defined set of activities. The most important success factor for Lean is not the activities themselves. Instead, they are the process interfaces with the outside. In this regard, it is critical to define:
(1) The inputs of the system that can be in the form of requirements, constraints on resources, time, competencies...

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[12] Edward Smith, The New Product Development Impetrative, HBR 2001
[13] Adapted from Edward Smith, The New Product Development Imperative, HBR 2001.

(2) The outputs that the system is supposed to deliver that can be in the form of manufacturing plans, tests reports, design documents...

The following two figures show the constraints and the inputs and outputs of the technology development process as a unique process (Figure 32) then those of a sub-process (Figure 33). The entire process works like if each sub-process was the customer of the precedent sub-process and the supplier of the subsequent sub-process in term of inputs and outputs.

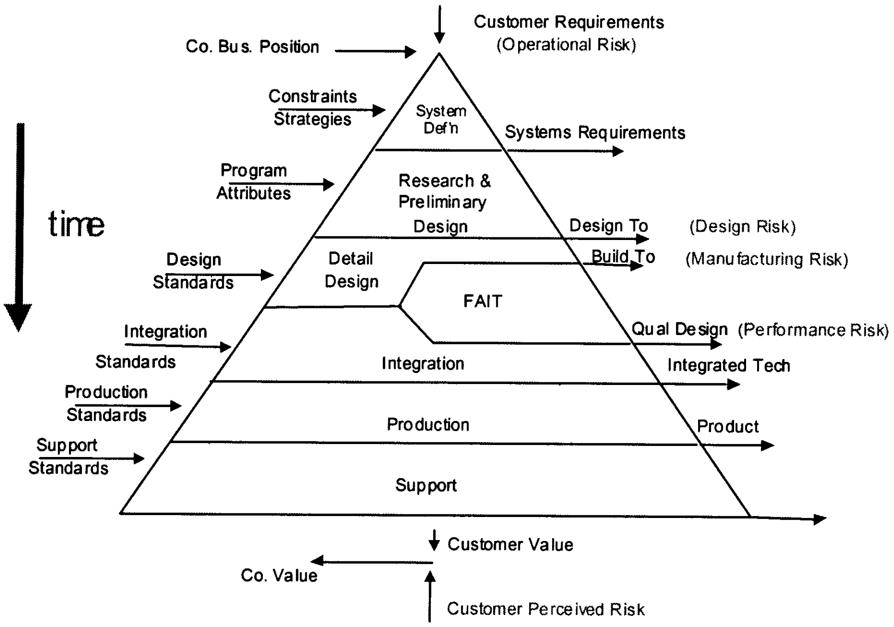

Figure 32: Technology Life Cycle Process
(Source: LAI, PDF Team)

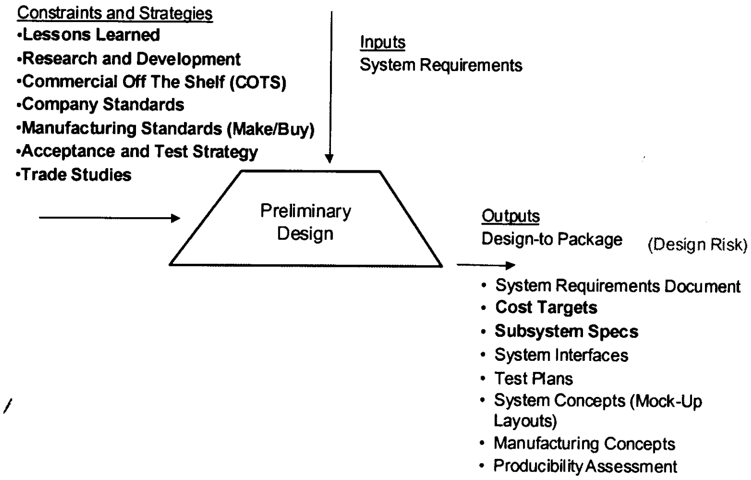

Figure 33: Sub-Process Inputs and Outputs
(Source: LAI, PDF Team)

2.3. STEP 3: Define Value

In *Lean Thinking*[14] value is defined as "A capability provided to a customer at the right time at the appropriate price, as defined in each case by the customer." An immediate difficulty presents itself when attempting to define value solely in the context of technology development. At the end of technology development process, value has only partially been realized. The technological system may satisfy the end user at this point, but it has first to be integrated in a recipient product and then manufactured.[15] Nevertheless, the value created by a new technological system can be seen in two different ways:

(1) Customer Value: The customer value is realized when the technological system has been integrated in a product and then manufactured. From the customer point of view, value can be in the form of:
(a) Performance: responding to a need that was not satisfied before. For example PALM's PILOT with it able hand-writing-recognizing technology responded to the needs that were not satisfied by the APPLE's NEWTON. Performance can also be seen in the form of quality, availability, serviceability, scalability, etc.
(b) Cost: cost of the technological system, includes the cost of purchase, maintenance, upgrades, disposal, etc.
(c) Timeliness: the ability of the company to deliver the promised product with the promised technology at the promised time constitutes value for the customer. This means that the company should in order to deliver the technology on time take into consideration not only development time but integration and production times as well.

(2) Enterprise Value: In addition to the customer value, the development of a new technological system and through interaction with other functions and processes in the company can create value for the entire enterprise:
(a) Synergies with other technologies: The value is this case can be seen in the form of cost savings by the using the same human and financial resources for developing different technologies (that are perceived as different by customers) or by using the same underlying concepts for different technologies.
(b) Preserving/Enhancing core competencies: Through technology development, a company can develop its research abilities and build its intellectual capital: two factors that determine the balance of competition between the companies. "What in the research pipeline of a company determines its future product portfolio"[16].
(c) Value for Stakeholders: In addition to the above two points, technology development creates value for the workforce (creation of jobs in engineering, production, sales...), stockholders (revenues, earnings...), suppliers (need for parts, knowledge....), etc.

For the purpose of the value stream in this thesis, only the direct value of the technological system being developed will be addressed. A plausible definition of value in technology development is the right information delivered at the right time, to downstream processes/customers.

Based on this definition, the value of technology development can be quantified by Form, Fit, Function and Timeliness. A technology delivered in the right form that fits the need and accomplishes the right function, at the right time for integration and production is a technology with maximum value. Similarly, value of a given step in the technology development process can be measured by the same functions since the entire process is simply a succession of simple sub-processes. The information requirements (FFFT) are:
(a) Form: Information must be in concrete form, explicitly stored.
(b) Fit: Information must be in a form that is (seamlessly) useful to downstream processes.
(c) Function: Information must satisfy end-user and downstream processes requirements.

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[14] James Womack and Daniel Roos, *Lean Thinking, Simon and Schuster*, 1996
[15] Identifying the value stream in product development, MIT LAI, PDF Team, 1998
[16] CEO of product Genesis, a Boston-based consulting company specializing in product development

(d) Timeliness: Information must be delivered at the right time.
The relative importance of these requirements depends on the user of the information (end user or downstream process) and his preferences.

2.4. STEP 4: Map the Information Stream

In technology development, information plays the same role that material plays in the field of manufacturing. Information is transformed within sub-processes the same way materials are transformed in different manufacturing stations. Information in many forms converges to define a final technology just as many parts come together to make a final product. Therefore, analogically, in order to create a value stream map for technology development, the first step would be to map information streams. However, the process is not as simple as in the case of manufacturing. "The process can be seen to be very strongly coupled, with many feedback loops"[17] (for example failed tests and reviews) which make it difficult to identify ahead of time critical steps. Furthermore, as information gets mixed at each step with the unwritten knowledge of the engineer, it is likely to undergo significant changes in form and function, which makes it difficult to speak about a unique stream of information.

However, even with these difficulties, tools can be used to reduce the complexity of the problem. For example, Design Structure Matrices (DSM) can be used to formalize the flow of information between sub-processes and identify feedback loops. More, it can be used to reduce the complexity of the system by a better organization of the steps and tasks. But this doesn't replace the value stream mapping and the elimination of waste, as it will be seen in the next steps.

In the next step (Step 5), The task of identifying and eliminating waste will be undertaken. Waste should be understood as the opposite of value creation. This implies that value should be mapped first, however, what have been done here (Step 4) is information steam mapping not value stream mapping which means that additional work needs to be done: "Identifying the value inherent in the information steams"[18]. A possible method is to identify the information required at the end of the technology development process and go backwards while asking at each step, how the sub-process contributes to the creation of the information required at the next sub-process. This allows identifying low-value steps from high-value ones. In addition to this, we can ask at each sub-process the question of the value added to the information and the changes made to it. If it is only a formatting process then the step is of low value, if the changes are important such as a test reports that determine if the design is good or needs rework, then the step is of high value.

2.5. STEP 5: Identify and Eliminate Waste

Once the flow of value has been mapped, the next step is to look for areas of improvement in value streams that prevent seamless flow between different phases of the process. These areas of waste can be in the form of useless processes where the output is not used by any other process, Roadblocks and Bottlenecks where inputs for the following processes are not available, or delays, etc.

Using analogies with the manufacturing world, seven forms of waste can be identified:

(1) Over-production: In the manufacturing world, it means the creation of product units that have not been demanded by the customer. In the Technology development world, it means the creation of information and data that have not been demanded by any other processes or that will be used by other processes but a long time later. Over-production is in reality a syndrome of a more critical problem: System Control. In a controlled system, only the information required is ordered and then produced. When a process is over-producing it means that the orders sent to it, to start producing, continue producing or stop producing are not generated or interpreted correctly: the system is not under control.

More, there is a difference with the manufacturing world: easy replication of information. Indeed, while it is very costly to replicate a product, replicating a design or a drawing is much cheaper and

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[17] Identifying the Value Stream in Product Development, MIT LAI PDF Team, 1998
[18] Identifying the Value Stream in Product Development, MIT LAI PDF Team, 1998

easier. This leads to over-dissemination of information, which is a waste with its own consequences and risks (that are not discussed in this thesis), because, in a perfect world only the right person should receive the right information at the right time.

(2) Inventory: As in the case of over-production, inventory has never been a problem in itself; instead it is a syndrome of other dysfunctions in the system. In technology development, inventory can result from information arriving too quickly to be transformed at reasonable time, complicated retrieval of information or outdated and obsolete information that is not used, but stored in databases theoretically for future use. But the nature of information and complicated retrieval and update make it difficult to use and in reality is never used.

(3) Transportation: This is also another waste drawn from a similar concept in the manufacturing world. In manufacturing, transportation is a waste because it is an unnecessary and costly process in terms of time, area usage and quality. Transportation reduces the quality of the products being transported directly, and also by making it difficult to identify defects, their sources, and to rapidly react to mistakes. In the Technology development world, transportation can be seen in the form of information incompatibility, which obliges engineers to "transport" information from one format to another. This process is capital and time consuming and can be the source of mistakes.

(4) Unnecessary Movement: In the world of manufacturing, unnecessary movement can be seen in the form of workers or parts making costly movements that could have been avoided through optimal layouts. In the technology development world, unnecessary movement can be seen in the form of engineers and scientists making movements because data and information weren't available in the right place or because they didn't have direct assess to them. Data and information themselves can be subject to unnecessary movement just like in the case of manufactured parts. For example reformatting that could have been avoided if data were prepared in the right format.

(5) Waiting: In the manufacturing world, waiting can be seen in the form of processes waiting for parts to be delivered in order to start transformation. Similarly, waiting in the technology world can be seen in the form of late delivery of information, making engineers and scientists wait for information to start their processes. For example, testing cannot start unless a prototype of the technological system is made available. In addition to this, waiting can result also from information being delivered too early, which may lead to rework as specifications and requirements may change after the delivery of the information.

(6) Defective Outputs: This waste draws from the manufacturing world where defective parts are obviously waste of resources. In the technology development world, defective outputs can result from lack of reviews, tests and verifications. In the worst case, this can lead to defective technological systems which oblige rework and redesign, the best example of this, is the airbags that inflate unintentionally creating thus a source of danger. This highlights the importance of having procedures of testing and verifying that outputs do satisfy the requirements that have been pre-established for them.

(7) Processing: In the manufacturing world, processing waste is a witness of a system that has not been well designed correctly, because some processes and steps can be redesigned while making savings in resources. Similarly, in the technology development world, processing waste can be seen in the form of processes that, though they change the information, do not really add value to it, for example, Excessive/custom formatting. These processes should be redesigned (for example included as steps in other more important processes) for savings.

2.6. STEP 6: Enable Flow and Look for Opportunities for Radical Change

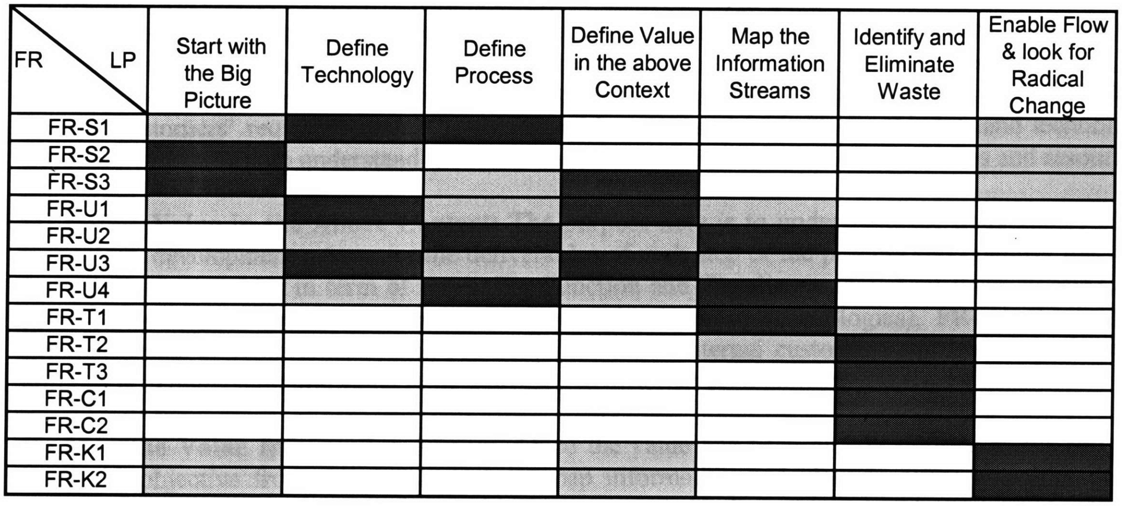
This sixth point has been included in the Framework for analogy with the Lean Manufacturing continuous improvement. In fact, once the existing process has been optimized and waste has been eliminated from the system, the only way to keep momentum in technology development teams is by looking for opportunities for change and identifying new ways of doing things that have not been explored before.

3. MAPPING OF LEAN ENGINEERING FRAMEWORK AND THE TECHNOLOGY DECOMPOSITION

3.1. The Mapping

In the previous paragraphs, we have presented the Lean Engineering Framework that has been developed within the LAI and applied it to the particular case of new technologies development. In CHAPTER four, we have presented a decomposition that links the strategic objectives of technology development to the underlying processes created to achieve them.

In this section, a mapping between the two approaches will be presented. It was decided so because some parts of the two approaches are so similar that it is believed that they will lead to the same outcome if applied. However, the main motivation was to understand to which extent, Lean principles can lead to the achievement of the strategic imperatives of technology. Based on this, the mapping is made only between lower level FRs of the Technology Decomposition and the Lean engineering principles that have been presented in the above paragraphs. The following table summarizes the results. It represents to which extent an FR from the Technology Decomposition can be correlated with a lean principle. These relations are not empirically derived nor validated, however, they seem acceptable from a logical point of view and they provide a good framework for discussion. The legend of the table is quite simple, dark boxes mean that the FR and the Lean principle are strongly correlated. The light color shows an existing link between the FR and the LP that is however less important than in the case of a red box. A non-colored box shows a non-significant correlation between the FR and the corresponding LP.



FR \ LP	Start with the Big Picture	Define Technology	Define Process	Define Value in the above Context	Map the Information Streams	Identify and Eliminate Waste	Enable Flow & look for Radical Change
FR-S1	▨	■	■				▨
FR-S2	■	▨					▨
FR-S3	■		▨	■			▨
FR-U1	▨	■	▨	■	▨		
FR-U2		▨	■	▨	■		
FR-U3	▨	■	▨	■	▨		
FR-U4		▨	■	▨	■		
FR-T1					■	▨	
FR-T2					▨	■	
FR-T3						■	
FR-C1						■	
FR-C2						■	
FR-K1	▨			▨			■
FR-K2	▨			▨			■

Figure 34: Mapping of Technology Decomposition FRs And the Lean Engineering Framework

Although, we could have made the mapping using lower-level FRs of the Technology Decomposition i.e. FR-S11…FR-K22, since these ones are more detailed than the ones we have used, and give more guidance in the design of a technology development system, we have chosen to use the middle level FRs i.e. FR-S1…FR-K2 instead. There are three main reasons for that:

(1) Because, the Technology Decomposition is not unique and there are certainly other solutions to achieve the same FRs. However, the higher the FRs, the lesser the number of solutions. Ultimately the higher-level objective of the Decomposition is unique.

(2) Because there is a causal link between lower level FRs and middle level FRs. Because the achievement of the lower level FRs leads logically to the achievement of middle-level FRs, if a strong link between a Lean principle and a lower level FR exists, then a link will inevitably exists between the Lean Principle and the middle level FR.

(3) Because the number of middle level FRs is much lower than the number of lower-level FRs (14 against 34), this makes the mapping easier and the study of its results more pertinent.

3.2. Explanation of the Mapping

As explained earlier, the dark color represents a strong correlation between the Technology Decomposition FR and the Lean Engineering Principle. The light color represents a correlation between the Technology Decomposition FR and the Lean Engineering Principle that although significant is not as important as in the case of a dark color. Uncolored boxes represent a non-significant correlation. The explanation of the mapping can be made either by explaining each FR using Lean Principles or by explaining each Lean Principle using the Decomposition. For the purpose of this thesis, the last solution will be selected:

(1) Start with the Big Picture: The objective is to understand technology development processes position within the company and with the technology life cycle without entering in details. This principle tries also to understand how the technology development can be coherent with the overall strategy of the company including other functions. Based on these remarks and the previous chapter, this Lean principle is highly correlated with FR-S2 (External optimization of the technology portfolio) and FR-S3 (Internal optimization of the technology portfolio).

(2) Define Technology: The objective here is to define the technology in term of its physical and functional boundaries as well as its physical and functional interfaces within the product. Based on these remarks, this Principle is highly correlated with FR-S1 (Understanding technology) as well as FR-U1 (Understand external customer requirements) and FR-U3 (Understand internal customer requirements).

(3) Define Process: The objective here is to define the technology development process in term of the activities to be considered and to define the process starts and ends and as well as the interface with other processes and in particular marketing and manufacturing processes. Based on these remarks, this Principle is highly correlated with FR-U2 (Meet external customers' requirements) and FR-U4 (Meet internal customers' requirements). It is also a highly correlated with FR-S1 (Understand technology) where the objective is to understand the technology constraints in term of competencies and resources.

(4) Define Value in the Above Context: The purpose here is to understand the deliverables of the technology development process or the deliverables of each step of the process and quantify the value from these deliverables in term of Form, Fit, Function and Timeliness. Based on these remarks, this Principle is highly correlated with FR-S3 (Synergies between technologies), FR-U1 (Understand external customer requirements) and FR-U3 (Understand internal customer requirements) where the purpose is to understand the value to be delivered to different stakeholders.

(5) Map the Value Information Stream: Once the value has been clearly defined in the previous steps, the objective from this Principle is to map information and identify different processes that transform technology and their interactions. Based on this, this Principle is highly correlated with FU-U2 (Meet external requirements), FR-U4 (Meet integration requirements) and FR-T1 (Meet target date) where the objective is to decompose different processes in the technology development in order to meet technology targets.

(6) Identify and Eliminate Waste: Once the value has been mapped in the previous step, the objective from this principle is to identify the steps that do not really add value to the final technology; eliminate and streamline them in order to improve the entire process. Based on these remarks, this Principle is highly correlated with FR-T2 (Minimize non-added value tasks), FR-T3 (Minimize reiterations in development process), FR-C1 (Optimize direct cost) and FR-C2 (Minimize indirect cost), which try to eliminate different forms of waste from the system.

(7) Enable Flow and Look for Opportunities for Radical Change: The objective here is to enable continual improvement by looking to new "out-of-the-box" ways for developing technology using mapping tools that have been developed above. Based on these remarks, this Principle is highly correlated with FR-K1 (Identify and capture knowledge) and FR-K2 (Use knowledge) where the objective is to enable improvement and change through investment in knowledge management.

4. ANALYSIS OF THE MAPPING

At a first look of the previous mapping, we can already see a diagonal matrix formed by dark boxes, this shows that the two frameworks are very similar (the diagonal matrix shows that each FR matches a Lean principle). This answers the first question: Lean principles do lead, in essence, to the achievement of technology imperatives because they are very correlated with the Decomposition design parameters and can thus be considered as a solution for technology requirements. In addition to this, the mapping highlights the following similarities and differences:

(1) The Technology Decomposition is broader than the Lean Engineering Framework. While the Technology Decomposition starts with the definition of a coherent technology strategy, the Lean Engineering Framework starts with looking to the Big Picture. However, the Big Picture in this case is different from the entire technology strategy of the company. It looks to positioning the technological system inside different functions of the company (the lifetime, the supply chain, the entire enterprise) but questions such as, 'which technology image should the company have?' or 'How the technology portfolio should be selected?', are not looked at within the Lean Framework.

(2) The Technology Decomposition is more helpful is assisting managers creating new technology development processes, while The Lean Framework is more helpful when improving an existing process. Indeed, by asking questions on what are the impacts of a new process on strategy, meeting customer requirements, cost, development time, and knowledge and competencies development, managers can decide wither a solution is worth implementing or should redesigned or discarded. However if a system for technology development is already in place, the Lean Engineering Framework allows its optimization by mapping value and eliminating waste.

(3) Both frameworks look at value and its optimization. However, the Lean Engineering Framework looks to value explicitly and tries to quantify it (as a function of the Function, Fit, Form and Time) and then optimize it by delivering the right information that satisfy the right need in the right form at the right time. The Technology Decomposition looks to value implicitly by avoiding strategic mistakes, satisfying external and internal customers, optimizing the time and the cost required to develop the technology and finally building and capitalizing knowledge to deliver more value in the future. It should be noticed here, that while this value optimization in the Technology Decomposition is more general and doesn't decompose the processes in their elementary elements and then try to optimize them globally, it is not because of the Decomposition itself but because of us. Indeed, we have stopped the decomposition at the third level of FRs and we didn't decompose the lower-level FRs any further. Additional future work would be to decompose these FRs further down (two or three levels). When done, this complete decomposition will certainly look to the decomposition of different technology processes into their different elementary steps and study how these ones can be optimized globally. At the low level, the Technology Decomposition will certainly join the Lean Engineering Framework proposing the same steps and the same methodology.

(4) To the question: 'Will we obtain the same results if we apply the two methodologies?', the answer is yes and no. Based on the above analysis, if we continue the Technology Decomposition further down, we will certainly obtain the same principles as those of the Lean Engineering Framework. However, if we look to the global technology strategy of a company, the Lean Engineering Framework is too narrow to be applied. The Technology Decomposition with its higher levels and its Technology Strategy Branch provides much more guidance on how technology issues should be approached in general.

(5) From a pedagogical point of view, the Technology Decomposition approach seems to be more appealing than the Lean Engineering Framework. This last obliges managers to learn the meaning of value in the case of technology development processes, which is a concept difficult to understand even

by researchers in the field of new technologies development. In addition, the Lean Engineering Framework obliges managers to learn value mapping as well as identification of non value-added activities and tasks. This process is very beneficial and educative for managers who are interested. Unfortunately a lot of managers lose interest as early as the first steps. The Technology Decomposition on the other hand, is very simple to understand. Through causal relationships that define the objectives of an organization (from a technology point of view) and then look for the best means and the solutions to achieve them, Technology Decomposition creates an appealing mental model in the mind of technology managers. More, it puts all technology elements from the highest objective to the most detailed procedure on "the same page". Seeing the position and the relation of each element with respect to other elements of the Decomposition is very important for managers who understand and acknowledge the importance of each element and its benefits to the corporation but fail in determining the organic relationships between elements and their relative importance. Sometimes, they even fail in making the difference between objectives and means.

(6) In the end, The two frameworks shouldn't be seen as competing. Instead, they are very complementary. The Technology Decomposition can be used in drawing the big picture of technology development and linking strategy to operational processes. The Lean Engineering Framework can be used for the optimization of each technology development in the company portfolio by mapping value, identifying waste and eliminating it.

5. CONCLUSION

In this chapter, we first introduced Lean Technology Development Principles that have been adapted from the Lean Aerospace Initiative. Then, we studied their interaction with the functional requirements of the Technology Decomposition that was developed a chapter earlier. Through a mapping between the two frameworks, many similarities and many differences were found. Both frameworks target the same objective, which is creating value for the company and it stakeholders through a better management, and organization of its technology development processes. The frameworks are also very complementary; the Technology Decomposition is more global since it first looks to the entire technology strategy of the company before looking to value optimization through waste elimination and continuous improvement. It is also more appealing through its functional requirements-development solutions approach. The Lean Technology Development Framework has a more scientific approach. By first understanding the technology and its positioning in the company, it tries to identify and measure the value at each step, it then looks to the global optimization of value from the process. For all these reasons, the two frameworks should be used together for a better design of new technology development processes or improving existing ones. This is exactly what will be done in the next chapter.

CHAPTER 6 CASE STUDTY: TECHNOLOGY DEVELOPMENT AT FORD

1. INTRODUCTION

So far, the Technology Decomposition presented in CHAPTER 4, as well as The Lean Engineering Framework presented in CHAPTER 5 are only theoretical frameworks that provide roadmaps for successful technology development. In this chapter, a case study will be presented where the above frameworks can be fully implemented. In a first phase, the current technology development process at Ford Motor Company will be presented. We will describe new technologies integration in cars through different aspects such as organization, management of resources and competencies, information systems and knowledge management and finally performance measurement. Special attention will be given to the role of suppliers and manufacturing in the development and deployment of new technologies. In a second phase, the current situation is evaluated using the frameworks and in particular the Technology Decomposition to identify the areas of weakness where improvements can be made. Based on this analysis, changes are proposed and a lean future state is imagined. As it has been presented in CHAPTER 5, in the lean state, the different processes are streamlined, waste is eliminated and resources are optimized.

In the end of the case study, a road map to ensure a smooth transition to Lean is presented. The three-year program is described in detail and use pilot project approach to reduce implementation risks. Also, new opportunities that will not be explored in the case study will be proposed for future work.

2. BACKGROUND

In this section, we will present the company as well as the organizational boundaries of the case, that will be studied further in the chapter.

2.1 Ford Motor Company

Based in Dearborn, Michigan, the Ford Motor Company was the second largest industrial corporation in the world, with revenues of more than $144 billion and about 370,000 employees. Today, operations span more than 100 countries. The company's core business is the design and manufacture of automobiles and their sale on the consumer market. Since Henry Ford had incorporated in 1903, the company had produced in excess of 260 million vehicles. Ford and its subsidiaries also engage in other businesses, including manufacturing automotive components and systems. Financing through Ford Motor Credit Company, and renting vehicles and equipment through the Budget brand. Ford's business is segregated in three primary operating segments.

a. Automotive

The Company sells cars and trucks and automotive components and systems throughout the world. In 1999 the Company sold 7.2 million vehicles worldwide. From, a brand point of view, Ford Motor Company brands are segmented by the markets they target:
(1) The Ford Brand for mainstream customers.
(2) Mercury for middle upper market (For customers, who want to differentiate from mainstream market without necessary paying huge price differences).
(3) Lincoln, Ford's, American luxury brand.
(4) Volvo, the Swedish carmaker that was purchased by Ford in 1998 distinguishes itself through safety as a main feature, in addition to the European luxury character.
(5) Jaguar, the sport brand of Ford.
(6) Land Rover, that was purchased from BMW in 1999 after five years of disastrous management by the Germans, targets the luxury Sport Utility Vehicles (SUVs) market.
(7) Aston Martin, targets the high end sport market.

Figure 35: The Ford Explorer, One of the Best Selling SUVs in the United States

b. Ford Motor Credit Company

Ford Credit is an indirect wholly owned subsidiary of Ford Motor Company. Ford Credit and its subsidiaries provide wholesale financing and capital loans to Ford retail dealerships and associated non-Ford dealerships throughout the world.

c. The Hertz Corporation

Hertz and its affiliates and independent licensees operate a worldwide car rental business. They also operate an industrial and construction equipment rental businesses.

2.2. The Automotive Segment

In the following and only if otherwise indicated, we will only consider the automotive segment where technologies that are seen inside cars and trucks are developed and integrated. The automotive segment is organized through a matrix organization, where employees wok for a functional division and a business line in the same time. There are two main functional divisions, the first, Product Development, takes in charge all activities related to the development and the introduction of new products and technologies, this includes Research, Design, Core Engineering, Quality, Environmental & Safety Engineering. The second functional division, Manufacturing, takes in charge all activities related to operations and logistics management, in particular: Vehicle Operations, Power train Operations, Advanced Manufacturing Engineering, Material Planning & Logistics, Manufacturing & Supply chain systems. In addition to the above divisions, the Automotive Segment comprises the following small functional divisions: Purchasing, marketing, Finance, Human Resources, Business Development, Process Leadership, Public Affairs, Government Affairs.

From a business lines point of view, the automotive segment is also divided into three business areas depending on the nature and needs of the end consumers: Ford Division (Ford Cars & Trucks), which targets average consumers, Premier Automotive Group (Mercury, Lincoln, Volvo, Jaguar, Land Rover, Aston Martin), for luxury and sport cars consumers and finally, Automotive Consumer Services Group, which includes Dealership Relationship Management, After Market Parts, Vehicle Servicing Business, Auto Insurance.

2.3. Consumers & Products

Products: Cars and trucks, 4.32 million total vehicles sales (24% of 18 million industry sales) in 1999, 40% cars and 60 % trucks.

Targeted customers: Individuals and companies who are likely to buy or lease cars or trucks.

Customer Needs: In order to achieve customer satisfaction, the product (car or truck) he/she buys has to be durable, low cost, fuel efficient, safe, enough space for cargo, exciting to drive and delivered on time. Ford has pushed the stake higher and quantified the above objectives to be satisfied by its products as follow:

High Mileage Reliability: 150,00 mile/10 year durability for cars and trucks.

Delivery of Low cost high Value products: (1) 50% life cycle cost reduction in selected major subsystems, (2) 36-month power train and 24 month vehicle.

Environment: (1) 50% customer fuel economy improvement for selected applications.

<u>Safety</u>: (1) Maintain five star collision index ratings, (2) No vehicles in the top ten list for theft. <u>Package Efficiency and Functional Styling</u>: (1) Vehicles to be among the leaders for interior package dimensions and cargo capacity, (2) Global recognition as the industry leader in functional styling. <u>Exciting, Great to drive Vehicles</u>: (1) Recognition by the Automotive Press that Ford products stand out in ride and performance assessments as competitively superior.

3. TECHNOLOGY DEVELOPMENT AT FORD

The current technology development process incorporates all the requirements mentioned above. However, the process has not been really optimized in the past. It was developed when the company had vertical integration for the technology development, i.e. the major development was in house. The current model of the company is to move towards horizontal integration, which will push the development of sub-systems to suppliers.

Currently, from the Company point of view, the technology deployment process is organized by traditional Mass Production vertical integrated system. The planning and deployment systems are very similar to the manufacturing MRP system. It starts with the strategy planning by consolidating the vehicle centers' wants and progresses to the final implementation. Figure 36 shows the current process map. The timing for the implementation is largely influenced by the next applicable (or available) vehicle lines application.

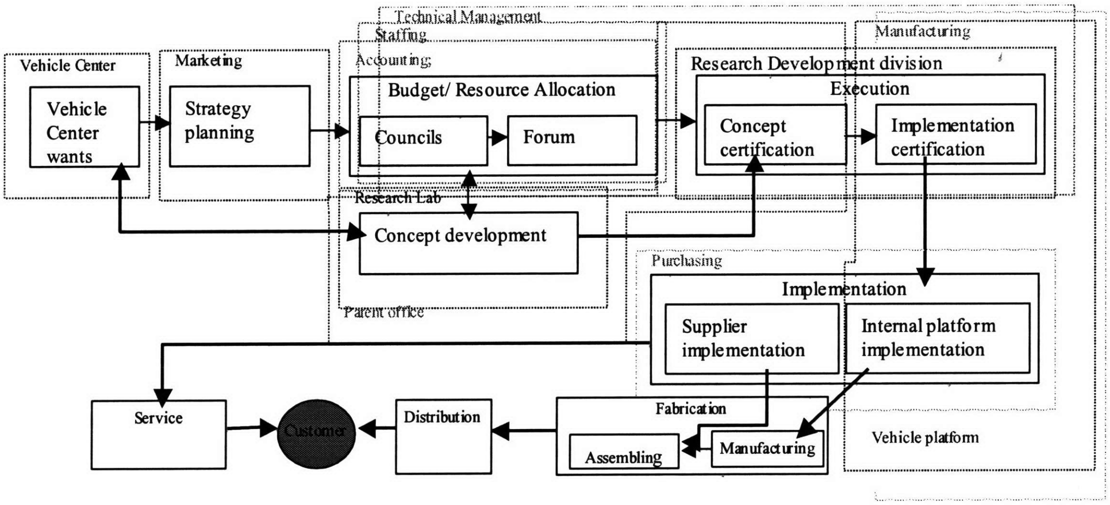


Figure 36: The Technology Development Process at Ford

In the following sections, the case study will proceeds as follow: The Lean Engineering Framework is applied as it has been described in the previous chapter. Then at the Issues' Identification step, in addition to the application of the Framework, an evaluation of the technology development process is made using the Technology Decomposition that has been developed in CHAPTER 4. This is one of the several applications where the Technology Decomposition can be used. The assessment is made through discussions with employees from Ford. In the future, a Decomposition-linked questionnaire will be created, this questionnaire will be used as a tool to verify the coherence of the assessments made by different employees and have therefore an assessment that truly reflects the real situation. After this assessment is made and the weakness areas are identified, the rest of the steps of the Lean Engineering Framework are then applied with a focus on the areas identified before.

3.1. Start With the Big Picture

3.1.1. Final Value of The Technology Development Process

As we have seen in CHAPTER 5, the value of a technology when developed is not realized unless it is integrated, manufactured and commercialized in a platform product. Nevertheless, we can study the value that a technology adds to the vehicle, from the final customer point of view: As seen by the consumer, this value can be categorized into 5 major categories as shown in Table 37 below:

Category	*Examples*
1. Increases functionality with increasing cost	GPS
2. Incremental functionality without incremental cost	Enhance durability
3. Reduce ownership cost without reducing functionality	Tire pressure control system
4. Mandatory functional improvement	Regulatory, corporate citizenship
5. Internal process improvement	Enhance time to market

Figure 37: Value Categories for New Technologies in the Eyes of the End Consumer

3.1.2. Value Inside Ford

(1) Supplier Integration: The Process creates value for suppliers at least at two levels of the process:

(a) Either, by proposing a technology that has been developed by its own engineering teams. In this case the technology must be certified by Ford through the Vehicle Centers which certify the technologies developed by the suppliers to a concept ready stage.

(b) During product implementation phase. The supplier is asked to bid to build parts of the subsystem of the new technology. The supplier develops the final design, product prototypes and also performs the attribute testing as specified by the Vehicle Centers. Once the Vehicle Centers certify the component, the suppliers develop the tooling to manufacture the products.

(2) Manufacturing, Customer Service and Distribution: The components for a new technology are selected for installation on specific car lines at the turn of the model year or a complete product change over. The components manufactured at Ford plants or at the suppliers' plants are ordered and delivered to the car assembly plant. The cars are delivered to the dealerships and the impact of the new components is studied on the selling decision of the customers. The service procedures for the new components are fully documented by Ford Motor Company, and the service personnel are trained to deal with any problems or complaints related to these components.

(3) Budgeting: Technology development projects do not require special funding as a whole. The department who gets a proposed project has to fund it on its own budget up until the technology is certified implementation ready (IR). The tooling and the engineering expenses for the new technology projects are governed by separate funds.

(4) Human resources: The teams who bid for the projects are usually formed by people from one or two departments. They are familiar and experienced in the underlying technology. The members of the teams had usually been working together on prior projects, occasionally the managers of the departments appoint external people to the teams. In addition, the members are usually dedicated to the projects until the Concept Readiness stage at least.

3.2. Define Product

Given the issues that have been underlined in the technology development and deployment at Ford and for the purpose of this study the technology final product will be defined as follows: A system which uses new innovative concepts and which is harmoniously integrated within the final product (the vehicle) physically and functionally to add value to the final user. Value means here, that given the price paid by the customer to have the technological system, he is satisfied with the function it performs.

3.3. Define Process

In its current form, the process can be decomposed into three sub-processes: technology planning, technology development, and product implementation.

3.3.1. Technology Planning

The driving force of the process is to combine customer needs and affordable targets in order to focus the corporate technology effort. The objective, based on benchmarking, is to implement at least 30% of the advanced portfolio and have 50% to 65% of the projects championed by the Vehicle Centers or Manufacturing Operations. The customer requirements, which are reported by the Marketing Department and the Vehicle Centers, are selected based on the Corporate Technology Leadership vision. The resulting goals are then distributed to nine Technology Councils ("Leadership organization and Spokesperson" for the area of technology) who prioritize them with the help of the Vehicle Centers and decide which technologies will be developed by Ford and which will be leveraged by outside suppliers. The Technology Forums (Technology Forums are the global, cross-functional, working subgroups of a Technology Council) in each Council draw the roadmap for each technology development. The Research and Vehicle Technology (RVT), the Advanced Manufacturing and Technology Development (AMTD), and the Design Center bid for the projects and are budgeted by the Councils upon approval.

3.3.2 Technology Development

After a technology has been planned and a bidder has been selected for its development, it is then developed to the Concept Ready stage (CR – feasibility of the technology is proved out) by the Advanced Research Organization at Ford or at the Supplier Research Centers. It then goes through a process of certification by the core engineering organization. The technologies that are not deemed to immediate application are book shelved (database) for future use.

3.3.3. Product Implementation

The technology developer will be responsible for finding the next available application opportunity for the technology. The implementation starts during the initiation of a new platform and it arrival to the product definition phase of the design cycle (Strategy Initiative (SI) of the program). The technology developer requires, at this stage, the program chief engineer (CPE) to sign the intention of implementation (DEAL) in its vehicle platform. After the DEAL is signed, the Technology developer will team up with the platform engineer to customize the technology to meet the platform objectives. Once the technology had been chosen by a platform for the implementation, the technology is given the status of "Implementation Readiness" (IR).

Some prototypes are then created. Testing is performed on the prototypes and all the attributes (reliability, performance, etc.) are verified. The tooling for the final fabrication is then developed with the help of the Manufacturing and Operations.

A DEAL (Deliverables Agreement Log): is an agreement with a potential implementer (champion) of a new technology that a program team would be interested in using the technology on a specific future vehicle application if the agreed functional and cost targets are met.

Concept Ready – CR: A Concept Readiness Assessment is a decision by a Technology Council that a technology basically works. It is not ready to be applied to a program.

Implementation Ready – IR: Implementation Readiness is an agreement by someone with authority to implement the new technology into a production program that the technology is ready to be transferred from AVT to the VC Program Team and the technology will be added to the program direction letter.

Figure 38: Some Definitions

3.3.4. Process Timing

the following table shows the various steps of the technology development process and the duration of each step. Depending on the technological system to be developed, the duration of the cycle can varies from 46 months (3 years and 10 months) to 138 months (11 years and 6 months).

Technology Phase	Product Phase	Task ID	Task	Duration(Months)			Task Precedence	Accum. Duration(Mnth)		
				Mean	Max	Min		Mean	Max	Min
Technology Planning & Resource Allocation	Plrduct Cycle plan	1	Colloect Product Center Wants	2.0	3.0	1.0		2.0	3.0	1.0
		2	Collect Marketing Wants	2.0	3.0	1.0		2.0	3.0	1.0
		3	Strategy Planning	1.0	1.0	0.5	1,2	3.0	4.0	1.5
		4	Technology Counciles	1.0	1.5	1.0	3	4.0	5.5	2.5
		5	Technology Forum	2.0	3.0	2.0	4	6.0	8.5	4.5
Technology Development		6	Concept Development	12.0	36.0	6.0	5	18.0	44.5	10.5
	Kickoff	7	Technology Bookshelf	1.0	2.0	1.0	6	19.0	46.5	11.5
	Strategy Initiative	8	Implementation Selection	6.0	12.0	2.0	6	24.0	56.5	12.5
		9	Concept Certification	4.0	12.0	2.0	7 or 8	28.0	68.5	14.5
	Strategy Confirm	10	Modify Design Documents	4.0	6.0	3.0	9	32.0	74.5	17.5
		11	Customize Technology for platform	6.0	8.0	3.0	9	34.0	76.5	17.5
		12	Sourcing	1.5	2.0	1.0	10,11	35.5	78.5	18.5
		13	Implementation Certification	1.0	1.0	1.0	12	36.5	79.5	19.5
	Product Implementation	14	Product Design	8.0	12.0	6.0	13	44.5	91.5	25.5
		15	Prototype Fabrication	7.0	9.0	4.0	14	51.5	100.5	29.5
		16	Attribute Verification	6.0	8.0	5.0	15,22	57.5	108.5	34.5
		17	Tooling	8.0	12.0	4.0	16	65.5	120.5	38.5
		18	Product Certification	5.0	8.0	4.0	17	70.5	128.5	42.5
		19	Supplier Technology Development	12.0	36.0	6.0	1,2	14.0	39.0	7.0
		20	Component Design	3.0	4.0	1.0	12	39.5	83.5	20.5
		21	Prototype developement	4.0	8.0	2.0	20	43.5	91.5	22.5
		22	Component Certification	4.0	8.0	2.0	21	47.5	99.5	24.5
		23	Component Manufactuing	1.0	3.0	0.5	22,16	58.5	111.5	35.0
		24	Order/Delivery	0.2	0.3	0.1	17,23	70.7	128.8	42.6
		25	Product lanuch	6.0	8.0	3.0	18,23	76.5	136.5	45.5
	Manufacture	26	Prodcut Manufacturing	0.1	0.2	0.1	25	76.6	136.7	45.6
		27	Product Assembly	0.1	0.2	0.1	24,26	76.7	136.9	45.7
		28	Product Distribution	0.5	1.0	0.3	27	77.2	137.9	46.0
	Delivery	29	Customer Delivery	0.3	0.5	0.2	28	77.5	138.4	46.2
	Service	30	Customer Service				29			
		31	Product Quality				30			

Figure 39: Technology Development Process Duration

3.3.5. Resources Involved in the Process

The following table shows the resources' utilization in the development process. Most of the resources go to the design phase (20%), Tooling (15%) and Prototype fabrication (7%).

Technology Phase	Product Phase	Task ID	Task	Workforce	Description of personnel involved	Assets	
						Budget (%)	Assets involved
Technology Planning & Resource Allocation	Product Cycle plan	1.0	Collect Product Center Wants	0.1	CE's of PDC, AVT, Support staff		CE's time
		2.0	Collect Marketing Wants	1.0	Marketing Department	0.5	
		3.0	Strategy Planning	3.0	VP's of VC's, PDC, AVT, Research, staff	0.0	VP's time
		4.0	Technology Councils	0.1	CE's from VC's, PDC, Core, RL	0.0	CE's time
		5.0	Technology Forum	1.6	managers from the above depts. Specialists	0.0	managers time
Technology Development		6.0	Concept Development	5.0	Research labs, Suppliers	5.0	RL, Core labs
	Kickoff	7.0	Technology Bookshelf	0.5	Research labs, Suppliers, Library	0.5	Library
	Strategy Initiative	8.0	Implementation Selection	3.0	Core Engineering CE	1.0	Core labs
		9.0	Concept Certification	3.0	Core Engineering - Engineers	1.0	Core labs
	Strategy Confirm	10.0	Modify Design Documents	0.4	Core Engineering, Suppliers - Engineers	1.0	Core labs
		11.0	Customize Technology for platform	4.0	VC's, Core, suppliers - engineers	2.0	, VC, Suppl labs
		12.0	Sourcing	0.2	Suppliers	0.5	Supplier labs
		13.0	Implementation Certification	3.0	VC's - CE, engineers	0.5	Core labs
	Product Implementation	14.0	Product Design	4.0	VC' s, Core - Engineers	20.0	Core Labs
		15.0	Prototype Fabrication	6.0	Advanced Mfg., Suppliers	7.0	Adv. Mfg. Labs
		16.0	Attribute Verification	2.0	Core Engineering, VC's	5.0	VC, Core labs
		17.0	Tooling	15.0	Company plants, Suppliers	15.0	tooling suppliers
		18.0	Product Certification	2.0	VC's	2.0	Core, VC labs
		19.0	Supplier Technology Development	4.0	Suppliers, Core Engineering	1.0	Supplier labs
		20.0	Component Design	2.0	Suppliers, Core Engineering	2.0	upplier, core labs
		21.0	Prototype development	2.0	Company plants, Suppliers	4.0	r, company plants
		22.0	Component Certification	2.0	VC's, Core engineering	1.0	core labs
		23.0	Component Manufacturing	8.0	Company plants, Suppliers	1.0	y, supplier plants
		24.0	Order/Delivery	0.2	Assembly plants, suppliers	0.5	Assembly plants
		25.0	Product launch	0.2	VC's	1.0	Core, VC labs
	Manufacture	26.0	Product Manufacturing	1.1	Company plants, Suppliers	18.0	y, supplier plants
		27.0	Product Assembly	0.6	Assembly plants, suppliers	4.0	y, supplier plants
		28.0	Product Distribution	0.0	Marketing Department	3.0	Assembly plants
	Delivery	29.0	Customer Delivery	0.0	Marketing Department	2.0	Assembly plants
	Service	30.0	Customer Service	2.0	Dealers	1.0	Dealer Service
		31.0	Product Quality	1.0	Core Engineering	0.5	Core Eng.
				100.0	People	100.0	percent

VC = Vehicle Centers, AVT = Advanced vehicle technology, PDC = Product development centers, RL = Research labs,
CE = Chief engineers, VP = Vice-President's

Figure 40: Technology Development Resources Utilization

3.4. Information Flow Mapping

3.4.1. Technology Planning Phase

In the technology planning phase, the product center requests the input from the vehicle center management for improvements in production manufacturing, then combined with the RVT benchmarking data and the input from the Office of General Council (OCG) Safety and Regulation office for the regulation forecast, it compiles a list of technology wants. The Marketing department also provides inputs for new marketing features to the wants list. The list is then compiled in the CREATE database for prioritization. The technology strategy of the company along with the marketing data such as competitor vehicle performance is used as a benchmark to facilitate the prioritization process. At this stage most of the communication is done through the CREATE database.

The Strategy Planning committee will update the technology strategy roadmap based on the corporate strategy as a document to highlight the corporate priority. The Technology council will compile the list to assign the high wants to each of the technology forums which will be shown in the CREATE database as the wants list. Core Engineering will develop proposals to bid on the wants list by entering the proposal into the CREATE database. Once a proposal has been accepted, then the technical department will budget the advance project into the next calendar year budget. The department budget meeting will be used to facilitate the process.

3.4.2. Technology Development Phase

The project manager, based on the allocated budget, finds the suitable resources to execute the project. Most of advanced projects require CAE, testing, prototyping, and CAD resources. The project manager initiates the process with either a planning meeting with the supporting department or emails to negotiate the resources. The Project engineer will act as the technical leader on the project to negotiate the design targets based on the affected attributes and comes up with a concept that meets the project objective. Most of the negotiations are done during face-to-face meetings. The project manager will track project progress internally with periodic review by hosting department. The project engineer, who comes up with a concept, communicates it to every involving party to synchronize the progress. This is done either by phone conversation or a formal progress report. Once the feasibility of the concept has been validated, the project engineer will contact the Intellectual and Patent Office to clarify any potential issues. Once all the Concept Readiness steps have been completed, the project manager will look for the implementation opportunity through personal contacts with platform management. If no platform is interested in the application, the project manager will start the book shelving process by requesting the Forum Chief Engineer to sign a Concept Ready (CR) readiness status with future implantation, then checks in all the data to the Knowledge Database by report form. In the case of a platform application opportunity, the Chief Program Engineer (CPE) will sign a deal document and project engineer will sign the CR form and enter into the implementation process.

In the implementation process, the project manager coordinates with the VDS and SDS authors for possible specification update. In case new parts need to be created, the project will request a meeting with the Core engineering for new parts creation. This is mostly done in face-to-face meetings. For the platform activity, at the program Kick Off (KO) stage, the program will be required to create a Product Direction Letter (PDL), program assumption document, program organization structure document. In the stage of Strategy Initiative (SI), the program will create a Product Attribute Leadership Profile (PAL) to document the functional performance. Then, a Quality Operation System (QOS) will form a road map to PAL. In the IR process of the technology, the program team engineer will work with the technology developer to customize the technology to fit the program objective state in PAL. If the new technology is to be outsourced, the new design will be transferred to the platform purchasing for supplier bidding by issuing a statement of the work to potential bidder. The bidding supplier will supply the proposal with available CAD and CAE data to combined purchasing and engineering selection. Early Sourcing Target Agreement (ESTA) will be issued to the awarding supplier with all available design documents. In the SC gateway, platform will down select the feasible technology list into a Strategy Confirm technology list for the production. When technology passes the SC gateway, the technology project engineer will initiate a process to change the technology status to Implementation Ready (IR) status. Most of the communications in this stage are through meetings and email.

3.4.3. Product Implementation Phase

In the design phase, most of the design communications are done through CAE, CAD and PIM. The Program Module Team (PMT) leader will track the progress and the decision-making through a PMT meeting minutes file, which is finally stores in a secured Web page for reference. The Program Attribute Team (PAT) will also track the performance though internal PAT meeting minutes file, which is also stored in a secured web page for reference. Most of the conflict will be resolved in the Program Steering Team (PST), which is led by the CPE assisted by functional managers. Once the product has been validated through the testing, the CPE will issue an Engineering Sign Off document to enter launch phase of the program.

3.4.4. Supplier Implementation

The supplier will communicate with OEM with common CAD system. At this stage, supplier will also need to develop the FMEA document to prevent possible failure modes. Design CAD data will be exchanged to and from the OEM and supplier chain with all attribute information. CAE data, test plan, test results will be shared by document or in electronic data form.

3.4.5. Manufacturing

In the manufacturing phase, most of the communication is done through the MRP system for part procurement, order allocation, etc. All communications are in electronic form except in rare cases, where the end-of-line replacement parts are procured by faxing orders.

3.4.6. Servicing

All the service bulletins are created in CD and distributed to the dealers to be used with the Service Bay diagnostic system. Replacement part orders will be issued by remotely connection of the Service division database to the OEM's supply channel. The quality data will be fed back from the dealer to the

Core engineering to monitor the defects. In case where out of normal warranty failures occur, the Core Engineering will ask the Part Return Center to request dealer to ship the warranty parts to the Warranty Return Center for inspection to determine the root cause of the issue and issue proper correction action. Some tier one suppliers may have direct access to the quality data from the dealer.

3.5. Metrics to Assess Technology

For each technology under development, Ford uses the following metrics to assess the technology fit within Ford overall strategy and objectives:

Objective	**Metric**
High Mileage Reliability	150,000 mile / 10 year durability for cars and light trucks
Delivery of Low Cost and High Value Products	50% life cycle cost reduction in selected major subsystems 36 month power train and 24 month vehicle
Improved Fuel Economy	50% customer fuel economy improvement for selected applications
Safety and Security	Maintain five star collision index ratings No vehicles in the top ten list for theft
Package Efficiency and Functional Styling	Vehicles to be among the leaders for interior package dimensions and cargo capacity Global recognition as the industry leader in functional styling
Exciting, Great to Drive Vehicles	Recognition by the Automotive Press that Ford products stand out in ride and performance assessments as competitively superior

Figure 41: Technology Assessment Metrics

In addition to the above metrics, Ford uses **12-panel chart** as the overall measurement matrix for every new product for its overall success or failure. For proprietary reason, the chart format cannot be presented in this thesis but we can only list the items in the charts. This chart contains all the vital information for the product success/failure index.

(1) Marketing, Sales & Service
(2) Market Equation
(3) Financials
(4) Currency Management
(5) Fuel Economy
(6) Environmental Actions
(7) Safety/Security
(8) Craftsmanship/Design
(9) Package & Ergonomics
(10) Attribute Targets
(11) Engineering
(12) Manufacturing Plan

3.6 Issues Identification and Analysis

As a first step in the improvement process, the objective of this section is to identify issues related to technology development within Ford. It will be taken into consideration development resources, cycle time, information flow, development tools, stakeholders' interests, and performance metrics. Important issues will be identified then in the following section, solutions to eliminate waste and implement Lean will be proposed.

3.6.1. Issues in the Information Stream Map

Although, the demand for a technology comes generally from the final user, the information stream map shows that not all the technologies that are demanded and developed to the Concept Certification stage are implemented. In fact only the technologies that find a platform for integration are implemented. The others are book shelved until interested platforms are found. This mechanism presents inefficiencies in a way that developed technologies are, in reality, invested capital and book shelving them means investing capital without return. In addition, and as we have seen it in CHAPTER 5, book shelved technologies are in fact a source of waste just like inventories of final products in the case of manufacturing.

A logical change would be to modify the process to a complete Pull: only technologies that have already a target platform for implementation will be developed. This will eliminate the bookshelf. However, this proposition rises two issues. The information needed to decide if a platform will be a recipient for a given technology is not available early in the technology development process. There is an issue of time horizon difference between technology development and platform development that need to be clarified

The implication of the platform development teams in technology development: More information is needed and relations between platform development teams and technology development teams need to be clearly assessed including the responsibility of each team in the decision-making process.

3.6.2. Issues with Supplier Integration

There are several aspects for suppliers integration: (i) using a bidding process where the suppliers are given specifications of the parts to be developed and constructed and the supplier's internal teams take to responsibility of developing the product. (ii) The supplier develops its own technology and licenses it to Ford. (iii) The supplier acts as the partner of Ford for the technology development. Ford provides incentives to the supplier with limited market, limited period of time for deploying the technology. The supplier can act as the agent to supply the technology to other automobile OEMs under a Ford licensing agreement.

In the second case, the issue of integration appears to be of minor importance. In the first case, however, where suppliers need to be involved in the design process at Ford, questions like the level and time of integration as well as intellectual property may arise. The third case is the experimental scenario for Ford RVT. It has both the advantage of alleviating the Ford resource constraint and early supplier involvement but there is no standard practice agreed upon by multiple stakeholders.

3.6.3. Manufacturing Integration

The issue is that manufacturing teams are not involved at an early stage in the technology design process. More, the customer-supplier between platform teams and technology development teams do not encourage partnership to introduce cutting edge technologies first in the market. Only after platform teams feel that they can't really do without a given technological system that they start asking for its integration in their platforms. The relationships between manufacturing and design teams are not clearly stated and need clarification.

3.6.4. Issues Related to the Core Competencies

In the technology development process, Ford has not identified a strong road map to link technology strategy with the core competencies in technology leadership to avoid competing on low margins mature technologies.

3.6.5. Issues Related to the Resources and Stakeholders

(a) The product cycle plan involves the high level executives of the company who dedicate part of their time in setting the direction for technology improvements that the final product would include. These plans are derived from the aggregation and prioritization of the customers needs.

(b) Depending on the priorities set by the high level planning committee, the technology councils set the directions, timeline for the technology diffusion into the final product.

(c) The technology forums select the project proposals depending on the merit of the alignment with strategy of the company.
(d) The budgeting process for the concept development will be included in the departmental budgets.
(e) The product design, development with focus on the particular vehicle will get budgeting from the Core and the VC's.
(f) The construction of the product prototypes will include budget form the Core and Advanced manufacturing.
(g) If the technology is passed to the supplier for development, they will support the cost of design and prototype manufacturing.
(h) The internal company plants or the suppliers do the final manufacturing; the manufacturing plants support the cost.
(i) The manufacturing plants will handle the distribution and delivery and the cost is mostly administrative.
(j) The dealers handle the customer service, but the final costs will come back to the company for the parts under warranty.
(k) The core engineering processes the customer quality data and handles the product improvements.

The large number of entities involved increases the complexity of the process. This leads to a long technology lead-time and increased inefficiencies. A streamlining of the organization might be proposed. The current Ford attribute based organization for the technology development has been proven to be less effective to achieve resource coordination and technology harmonization than PVT team structure.

3.6.6. Issues with the Cycle Time

The biggest time delay appears to be in the technology planning phase. This process starts in January by collecting the customer wants then goes through various technology planning committees and forums for the technology selection and departments' assignment. By September, each department knows the budget associated with the progress in the technology development, and then the department starts the annual departmental budgeting process to submit the department budget for the approval within the next year operational budget in October. The budget will be finalized by the following February by going though the whole corporate budgeting process. Meanwhile, the approved technology concept development will start in January the following year. Time for technology development depends on the complexity of the technology. Internally, Ford normally categorizes technologies into three categories: re-applications (average 6 months lead time), emergent technologies (12 months lead time) and Inventions or basic research (36 months plus).

Once a technology has been developed, the developer has to sell the technology to the next applicable platform. If the Chief Engineer (CPE) of the platform agrees to study this technology application in the Strategy Institutive phase of the platform, he will sign a "Deal". Otherwise, the new technology will go into the technology bookshelf for future applications. If a "Deal" is signed, then Core Engineering will modify the necessary design specifications, testing procedures and part numbers to support the technology. The platform team will deploy platform resource to perform the feasibility study for application. In the Strategy Confirm (SC) Stage of the program, the compatible technology will be selected then the technology developer can declare this technology implementation ready (IR). If the technology needs to be outsourced for manufacturing, before SC gateway, the manufacturing supplier for the new technology needs to be identified.

Once through the SC gateway, the new technology enters the design, attribute testing and certification phase and finally moves into the manufacturing and distribution phases, Once the product is sold to the end consumer, the Dealer will service the product under the manufacturing warranty plan. Quality data will be reported back to the Core Engineering for synthesis.
Other major issues related to the timing:
(a) The timing for the technology development will not match the intended application platform cycle time.
(b) Overlap of the technology budget planning and the department budget planning.

(c) Technology compatibility issue for platform application requires longer time to address.
(d) Supplier is not involved in the technology development process. This necessitates long time to transfer the technology.
(e) Some of the technologies may not be compatible with the suppliers existing manufacturing resource, therefore will have to retool their manufacturing line and production may not be possible at desired price.
(f) There is no assurance from the supplier for the potential quality issues in the new technology.

3.6.7. Issues with Information Management

There is no integrated system that can provide an overall management for technology development. In each step of the process and even within a given step, the information flow relies on different means with poor interconnection and communication, which does not ease the integration. In addition, there is a weak knowledge management system to keep track of knowledge form each project. One identified problem is the recurrent 'reinventing the wheel' in the technology development process. The other is lack of knowledge exchange among Ford, supplier and manufacturing.

Standard Process and Work order:
There is lack of common practice and work order among many Ford departments for technology deployment. The huge discrepancies among the task definition, resource allocation, gateway review from each of the department has resulted in misalignment of the deliverables and resource allocation.

3.6.8. Issues with Metrics

Corporate metrics are well defined at Ford and are divided into five categories:
(a) Corporate strategy: shareholder value added, net revenue growth, business structure, and total cost change.
(b) Market Data/Competition: Ownership satisfaction, Customer loyalty.
(c) Market strategy: Brand value share.
(d) Operations strategy: Nimble organization.
(e) Regulation: Corporate citizenship.

However, the main issues in this area is that when translating strategic metrics at the senior level to the local level, the local metrics measure local issues creating local optimization problems where the corporate wide view is muddled and sometimes lost.

Regarding the technology process, the translation of high-level metrics is made through the measurement of the risk the new technologies would have on Ford and its organizations.

3.6.9. Issues with Technology Tools And Support Functions

In the technology planning phase, we note the following issues:
(a) No common database to manage the technology planning which includes the cost- benefit analysis, risk assessment, market trend, competitor position and internal brand requirement.
(b) The Vehicle team CE sometimes implement technologies on ad-hoc basis without particularly following the technology strategy of the company.
(c) The technologies that are implemented on some vehicle lines do not permeate easily to the other platforms, since there is no common database for the implemented technologies and the lessons learned in the process.

In the technology development phase, the following issues can be noticed:
(a) No standard definition of Concept Ready status.
(b) No standard work resource estimation.
(c) Low priority for CAE, testing resources.
(d) No common database to manage the concept, approval, resource planning and development process.
(e) No database to store all CR technology.
(f) Knowledge database contains no lesson learned or development process information.

(g) Purchasing take long lead times to process and does not contains technical information.

In the integration phase, the following tools' issues can be noticed:
(a) No manufacturing database to assist design decision.
(b) No common CAE and CAD tools.
(c) PIM is tedious to put in or to obtain information.
(d) Lack of CAE tools to correlate to the test results.
(e) No CAM tools to transform CAD data to manufacturing data.
(f) Changes in design during launch are not always updated in CAD, database.

When considering supplier integration:
(a) No database to manage supplier technology.
(b) No common CAE tools between supplier and OEM.
(c)No Web site to manage supplier FMEA, testing data, process control data, CAE data, etc.

When considering the manufacturing phase:
(a) Manufacturing database is a separate system.
(b) Lose track of vehicle in the process of delivery.

In the servicing phase, there is no database to share service requirement with Ford product development team.

From the nine different types of issues identified in the above section, we could finally draw a summary picture of technology development process at Ford as follow:
(a) Absence of the pull process that allows producing only when needed and absence of synchronization between technology development and vehicle cycle plans.
(b) Weak definition of suppliers' integration and weak implication of manufacturing teams in product design.
(c) Complex organization that lead to longer lead times and waste of resources.
(d) Poor management of information flow and fragmentation of systems.
(e) Weak knowledge management and transfer.
(f) Fragmentation and loose management of technology tools.

3.7. Weakness Identification Using the Technology Decomposition

The following figure shows the Technology Decomposition where all the FR-DPs are represented on a unique page. However in addition to this, we have shaded the lower level FR-DPs with three different shades representing respectively how good is the score of Ford with respect to each FR-DP pair. This evaluation has been constructed based on an valuation of the Technology Development Process at Ford using interviews and discussions with managers and executives. In the future, this evaluation will be Ford employees themselves who will then discuss each FR-DP pair and the evaluations they have given to their own processes. This will provides a good baseline for discussion, brainstorming and ultimately improvement.

In this evaluation, only the lower FR-DPs pairs have been assessed, this stems from the construction of the technology decomposition itself. In chapter 3, we have shown that the Decomposition is organized in a way that the achievement of lower FRs leads logically and organically to the achievement of higher level FRs, therefore evaluating the lower FRs is logically enough to assess the ability of the technology development process to achieve the strategic imperatives of technology development.

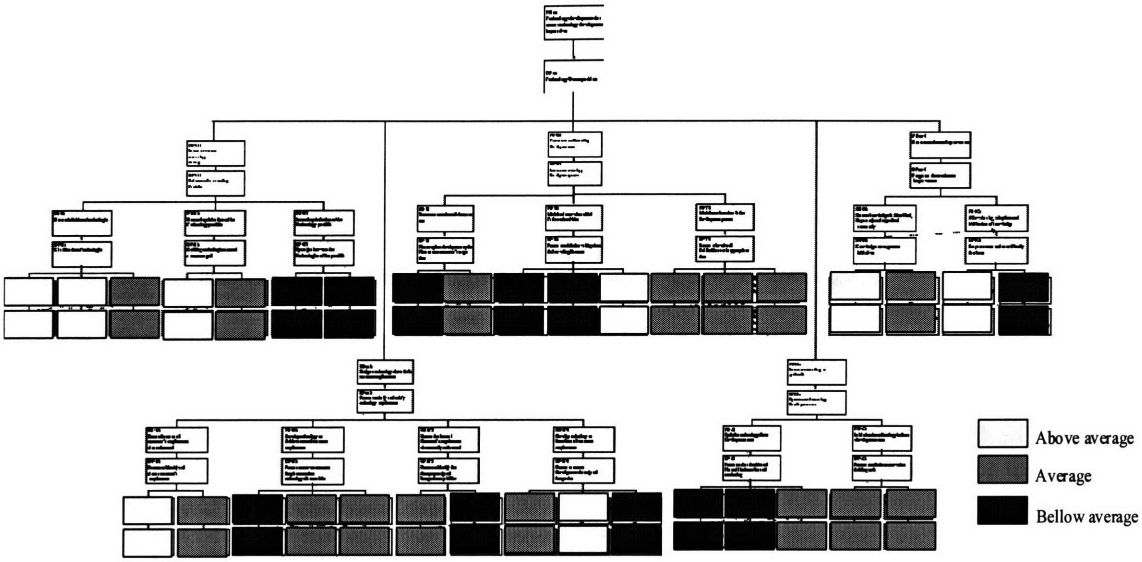


Figure 42: Technology Development Process Using the Technology Decomposition

The evaluation made using the Technology Decomposition shows very similar results to these obtained using the Lean Engineering Framework. In addition to that, we can note:
(a) Lack of compatibility among the technologies. The program team has to do the integration job.
(b) Ford organization has moved from a vertical integrated organization to a horizontally integrated organization with more than 70% of the parts outsourced. Suppliers want to have the right to share the new technology and designs with their potential OEM customers in order to reduce costs. Due to the exclusiveness requirement for the Ford developed technology the suppliers have to develop new manufacturing lines to supply the products to Ford Motor Company.
(c) No defined upstream value definition for new technologies.
(d) Takes too long to implement a new technology. Technology that's developed has no target product line for implementation.

4. LEAN IMPLEMENTATION OF TECHNOLOGY DEVELOPMENT AT FORD

4.1. Lean Vision

In the following section we will draw in detail the picture of the technology development process at Ford when Lean concepts would have been implemented and we explain how these concepts will impact the different entities and processes involved in the process. The whole technology development process model shall switch from the "Water Fall" model to Adaptive model in order to enhance its speed and endurance for changes. It shall switch from a task oriented process model into a time-bounded performance driven process. Information shall flow freely within the multiple parallel processes and with synchronization of gateway performance measurements.

4.1.1. Lean Value Stream Map

The analysis of the current state of the technology deployment process has revealed non-value adding and non-necessary steps and practices. The lean state of the technology deployment process relies on suppressing all non-value-added activities when they are not necessary.
A vision of a lean value stream map follows:

(1) Technology Planning Phase: The two first steps remain unchanged: the Marketing and Vehicle Centers provide the Strategic Planning with the customer wants. The Strategic Planning develops and updates a technology portfolio in accordance with the corporate technology leadership vision.
The technology portfolio is then made available to the platform development team leaders who decide whether or not to host one or several of those technologies. Once a platform team leader has accepted to host a technology, a technology development team leader is then nominated. He reports directly to

the to the Core Engineering Chief Engineer. The technology development team leader has the required authority to compose his team by pulling the needed resources from individual supporting organization. He is funded by the host platform development organization (customer for the technology).

(2) Technology Development Phase: The technology development team leader is in charge of determining the outsourcing strategy for that particular technology. Three possible outcomes arise according to the strategic importance of the technology: (1) in-house development, (2) partnership with the supplier and (3) implementation of a supplier-developed technology.

In cases (1) and (2), the technology development team leader manages the concept development to the Concept Ready stage jointly with the supplier or not. If the feasibility of the technology is proven out, a complementary set of certifications is conducted prior to implementation (Implementation Ready stage). The modifications of this part of the process are the removal of the bookshelf, since the technology has already found a host platform, and the management of the integration of the suppliers at early stages.

In case (3), the supplier has already conducted the concept development phase; the technology is de facto Concept Ready and has to be certified to the Implementation Ready stage.

(3) Product implementation Phase: This part of the process takes into account the joint development with the platform development team and the early integration of the downstream operations (manufacturing and assembly) as well as the suppliers.

4.1.2. Lean Cycle Time

In comparison with the process in its initial state and based on the steps that have been modified or completely suppressed from the value stream map, the average lead-time will be reduced by an average of 12 months, explained as follow:
(1) Replacement of the Technology forums and Technology Councils by a unique Technology deployment team: reduced time by one month.
(2) Suppression of the bookshelf and synchronization of the Technology deployment process and platform development: reduced time by one month in average.
(3) Since the bookshelf has been eliminated, the step of implementation selection can be reduced by 4 months.
(4) Since the platform for the technology is already known, the step of customizing Technology to allow it to fit in the platform is eliminated: reduced lead time by six months.

4.1.3. Lean Resources Management

In addition to reduced lead-time, the new lean map reduces the number of structures involved in technology development and increases the effectiveness of existing ones. The new lean map reduces the waste of resources as follows:
(1) Streamline non-value added Structures: It is proposed to eliminate the Technology councils and the Technology Forums. The reason for this is to have a better synchronization of the technology development with the platform development and a global consistency in the technology development process.
(2) New Organization and Changes in the Decision-Making Process: In the Technology Planning phase, the Strategic Planning issues a portfolio of technology that are in line with the company's vision. Currently, the nine Technology Councils bid to get the attribution of technologies to develop. Each council gets then a portfolio of technologies to develop even without an identified host platform.

The new organization eliminates these structures. The Platform development teams select technologies to develop. The next step is the nomination of a technology development leader with the duty to develop the technology in question for a particular host platform. He reports directly to the top management and has the required authority to select his team among the design organization. The funding will be provided by the platform development.

Such a structure allows an effective allocation of resources (financial, time, human) since the objectives and time frame are clearly defined and consistent with the customer's constraints (platform development team). Moreover, the technology development team is fully autonomous and dedicated to this unique task.

After the completion of the project, the technology development team leader will have the responsibility to make the technology available to any other interested platform (standardization and re-use).

4.1.4. Standardization of the work process and work order

Ford shall standardize the technology development process and associated work order. Work order shall include the task definition, method, time duration, staffing requirement, resource utilization (such as testing equipment, number of the tests), budget, verification and validation tools, performance targets. This standard process will specify the 'what, how, who, where and when' of the technology process to ensure work quality.

4.1.5. Information Systems and Knowledge Management

Three areas should be considered when looking at the information system in place:
(1) Drivers for information flow: In the case of Technology deployment process, information can be in the form of orders to perform actions, authorizations to move to the next steps (certification) or in the form of drawings (for an application) or data to be exploited (Customer satisfaction surveys). Moreover, the technology development process can be considered as the process of transforming information just as manufacturing with material and all sources of waste within this process should be eliminated.

In the value chain, and through the elimination of unnecessary entities from the process as well as unnecessary activities, fluidity in the flow of information is ensured in a way that at any time, information is being processed by a given entity in the organization.

The elimination of the bookshelf, which was, in reality, an in-progress inventory in the technology implementation process implies that the information system will be able to link the technology development teams and platform teams in a full pull approach.

(2) Information support: In this area, the different systems currently used are fragmentized and not completely connected. Under the new lean map, a unique and global information system will be created linking the entities described above and particularly the platform teams.

(3) Knowledge Management: A special interest is given to the building of an efficient and integrated Knowledge Management process based on the new information system. Such a process relies on a systematic capture of all the relevant knowledge from each step during the technology deployment process and on its categorization and storage in dedicated databases. Standard procedures will be defined to leverage this knowledge by allowing an affective dissemination (widespread and reliable network) and above all, inciting its reuse whenever possible.

Keeping a record of all the key persons involved in the different projects as well as their roles will emphasize tacit knowledge sharing. Networking events shall also be organized periodically between different development teams in order to homogenize and promote best practices. The technology process related knowledge such as budget; resource utilization; schedule, meeting minutes from previous project should be kept in knowledge database as the base line information for new project planning.

4.1.6. Lean Supplier Integration

In the previous sections, we have identified a need to clarify the supplier policy regarding the technology development process. Depending on the strategic importance of the technology (core competence or not, follower strategy or leader strategy) and on available development resources, we propose three ways to deal with the supplier integration within the technology development process.

(1) Non-Differentiating Technologies: For non-strategic, non-core technologies ("commodity" and mature technologies, ex: wheels, HVAC, electric, glasses) or technologies for which Ford has none or very low knowledge (non-strategic but necessary technologies that would take too long and too many resources to develop inside, especially when a competitor has already launched it: follower strategy; e.g.: ABS), a complete development of the technology by the supplier is better suited.
Ford will implement the technology under the supplier's license. In addition, Ford will manage the integration on time in platform development (customization/design modification and manufacturing coordination).

(2) Highly Differentiating Technologies: For highly strategic technologies involving Ford's core competencies (e.g.: engines, electronic systems), an in-house development of the technology is the most suitable solution. Only the design of some of the parts will be outsourced to different suppliers according to the classical scheme: Ford keeps the control and the knowledge of the global process.

The integration of the suppliers from the design step will be needed. A similar integration of both Ford's and suppliers' manufacturing teams will be performed.

(3) Moderately Differentiating Technologies: For technologies that do not have a high strategic importance but consolidate Ford's products differentiation, and for which certain knowledge needs to be kept (typically technologies that are not threatening for Ford if copied, but somewhat lessen Ford's competitive advantage, e.g.: such a light weight bumper beam), a development in partnership with fabrication supplier is a good alternative to an in-house development.

(4) System Level Technologies: The essential system integration knowledge (such as Design Standard, Quality data, Design Guideline) shall be centralized within Ford Core Engineering to avoid weakening its product competitive advantage. Tier one system integration suppliers shall have limited access to facilitate their work on Ford product.

(5) Fundamental Research: Ford Science Research Lab. shall concentrate on the fundamental technology development by aligning its development and resources with global research institutes. Fundamental research shall be managed by core engineering to ensure the continuous flow of the pull system.

(6) Technology Procurement and licensing: Ford shall establish a system for the procurement of the technology through the supplier or the other sources. Ford core engineering shall determine the buy or make decision through technology benchmarking activities. Technology licensing to the supplier or competitor OEM may be realized though selection of the key supplier as the implementation agent in order to achieve the benefit of economy of the scale for the production. This technology loyalty shall be partially rewarded to the Core Engineering to fund future technology development.

To address the intellectual property issues, Ford will have to revise the supplier contract structure. The technology will have to be jointly patented and the contract might include a clause according to which the supplier agrees not to sell or implement the technology for another OEM without Ford's explicit agreement and for a given period of time. However, this might prove not to be sufficient to ensure the supplier's loyalty. Above all, the potential partner must be part of a network of preferred suppliers sharing common values and loyalty. The issue of suppliers and the OEM-Suppliers partnership will be discussed more in detail in the next chapter.

4.1.7. Lean Metrics

In addition to the metrics that are used currently by Ford, we have identified the following additional metrics that measure how lean is the development process. It is important to note this is a non-exhaustive list of indicators:

(1) Lead time: time to market.
(2) Quality: Quality will be measured by the degree of matching customer wants and the degree of competitive advantage to competing technology.
(3) Market penetration of the product.
(4) Scrap rate: Scrap rate will be measured by the cost of the bookshelf technology with more than 3 years shelf life.
(5) Return on investment: Technology shall be rationalized to the return on investment by proper estimation of the added revenue associated to the deploying technology. The intangible value such as the increase sale volume, strength of the brand position will be converted to ROE.
(6) Consumer queue: Consumer queue will measure the consumer wait time in queue for technology and the number of consumers waiting in the queue for new product with the desired technologies. It shall also measure how many customers left the queue to adopt competitor product based on technology availability).

In this section, areas of improvement in the Ford Technology development process have been identified and a future lean state has been constructed. This future state should be dynamic in constant improvements to cope with external and internal changes. However, a very important aspect in the success of lean implementation is the roadmap chosen for the implementation. This road map will be analyzed in the next section.

4.2. Road Map to Lean

In this last section, a roadmap that will allow Ford to achieve the Lean Technology Development State will be presented. The transformation plan includes five sub process improvements: the business strategy for technology deployment, the process updates from push to pull with alignment to value stream, the Standard of Work (SOW) for technology development, the reduction of the technology bookshelf, the enhancement on technology management system, the enhancement on information flow and knowledge management system and the supplier technology strategy. The upgrade plan will be based on a 3-year schedule, which will be defined based on the priority and interdependency among the sub processes.

4.2.1. Business Strategy for Technology Development

The business strategy will be updated to place more emphasis on (1) the speed of technology deployment versus the cost of the deployment process, (2) the individual technologies that will strengthen the brand position to meet target customer wants rather than the generalized technology enhancement which weakens the brand position, (3) brand technology portfolio rather than individual uncoordinated technologies, (4) the short term deliverable than long-term deliverable to accommodate the quick market changes so they can complement each other and build the foundation for all strategy upgrades, (5) delegation and leverage of application technology responsibilities and resources to implementation organizations such as PD or suppliers.

All brand-oriented technology emphasis shall be aligned with identifiable corporate core competence in order to deliver the long-term success of the corporation.

4.2.2. Process, Organization Move from Push to Pull Approach

RVT will create a cross functional Technology Center (TC), with delegated Technology Managers (TM) who will be assigned the responsibility of brand/platform. All technology budgets shall be allocated to Technology Center including both the developing and implementation budgets. The Technology Managers have the full responsibility of (1) technology identification, (2) maintaining the compatibility between vehicle cycle plan and the technology cycle plan and (3) the final implementation of the technology. The Fundamental Research Department shall be under the responsibility of associated Attribute TM in Scientific Research Labs who will report to Technology Center's Chief Engineer. Individual supporting organizations will be budgeted based on the resources requested by the Technology Manager. The Technology Manager will assign a fair rewarding rating for each of the supporting organizations, for each successful technology deployment.

The full process, organization and rewarding sub process updates, will be formulated by the end of the first year, a pilot will be launched in key areas during the 2nd year with full implementation in the third year.

4.2.3. Standard of Work (SOW) for Technology Development

For each technology category, a standard of Work (SOW) statement shall be identified, defined, agreed and standardized across the technology deployment span in the first year of the phasing. In the second year, all new projects will be budgeted, executed and managed based on the SOWs for technology development organization. In the third year, this SOW process shall deployed to incorporate both supplier and internal implantation organizations such as PD, Manufacturing.

4.2.4. Reduction of the Technology Bookshelf

The reduction of the average time spent by technology in the bookshelf will be phased in a 7-year period program. In the first year phase, all technologies shall be identified by platform or by supplier for potential use, any technology without potential customer and with more than 3 years spent in the bookshelf will be transferred to an outside technology-licensing agent. The shelf cycle will be reduced from 7 years to 5 years in the second year and to 3 years in the third year. The business unit will be billed back 20% of the project cost for future technology being removed from the bookshelf.

4.2.5. Enhancement on Technology Management System

In the first year, Ford will enhance the capability of the CREATE database to expand its capability in terms of project timing plan, budgeting plan and resource allocation plan to cover the lifetime technology deployment processes. Also in the first year, CREATE capabilities will be extended to incorporate the department resource capability profile, which includes the personnel, hardware and software equipments. In the second year, the Technology Manager will use the SOWs as the base for project management. This includes budgeting, planning and developing phases of the technology. The Technology Manager will draw proper resources based on the resource capability profile from supporting organization. In the third year, this system will extend its operations to include the deployment and servicing phase of the technology.

4.2.6. Enhancement of Information Flow and Knowledge Management

In the first year, after a diagnostics of all existing systems and determination of the best information system solution to be implemented, the system will launched in a test phase on one chosen technology deployment. This phase will serve an opportunity for improvement and refinement of the proposed technical solution as well as a learning tool for users of the global information system to be created. At the end of this step an evaluation of the system by all its users will be made.

In the second and the third years, the system will be extended to include the majority of functionalities in technology development such as certification, coordination with platforms, etc. Information processes will be integrated in a unique global information system that will be extended to include suppliers, manufacturing and dealers.

A knowledge management program will be launched using the same timeframe following the deployment of the information system and will applied in a test phase to a selected technology.

4.2.7. Supplier Technology Strategy

In the first year, the Technology Manager will select the technology development partner based on supplier's capability and strength. The Technology Manager will host this selection process with the support of Core Engineering, PD, Purchasing staffs and corporate Intellectual property lawyer by forming preferable technology development partnership. The second year will focus on the formation of the supplier technology chain by purposely aligning supplier tiers. Tier one suppliers will be assigned with the subsystem integration technology responsibility while lower tier suppliers will be assigned the component level technology. Ford will co-develop the technology based on supply's technology tiers through skip level leadership. The basic structure of the technology chain is layered interface instead of hierarchical tree to avoid "Intel inside" scenario (Value of new PC's is based on the

Intel chip they use rather that the OEM label). Ford will select key partner supplier to act as Ford technology implementation agent for other OEM's to gain both "economy of scale" to lower technology costs and obtain loyalty from other OEM's.

5. CONCLUSION

The proposed transition to lean is expected to improve the efficiency for the Technology Deployment Process and reduce the cost of introducing new technologies. Cost reductions are due mainly to three reasons:
(1) The reduction of the lead-time, which translated in other words means creating the same technology with less resources.
(2) The streamlining of the organization that eliminates costly redundant entities.
(3) The reduction of the time spent by technologies in the bookshelf. This creates two revenues: a technology start generating revenues as soon as it is used and second if a technology is not used, it generates revenues through licensing fees.
Although these revenues depend on the considered technology, revenues are estimated in some hundred millions dollars.

In addition, the proposed pull process will create the necessary incentives for resources optimization by producing only what is needed.
From the information point of view, the proposed changes (a unique global information system) will allow a better streamlining of the work and encourage the involvement of all stakeholders of the process.

Knowledge management will certainly play a very important role in the innovation process and has been given consideration in the proposed changes toward lean trough the creation of a knowledge management system.

Furthermore, special attention has been given the impacts of the changes to be made in order to ensure a smooth transition to lean.

Finally, Lean is also constant improvement. The changes proposed in this chapter although very important and have considerable impacts on the organization don't represent an end but are the start point for new improvements.

CHAPTER 7: POLICY RECOMMENDATIONS FOR TECHNOLOGY SUPPLY MANAGEMENT

"Technology and Globalization are deepening the need for manufacturers and suppliers to become long-term partners in developing new technological systems. But what is the right mixture for success?"[19]

1. INTRODUCTION

CHAPTER 2 presented several technological trends that are impacting virtually all industries and corporations. Although, the focus was on the customer side (many of these trends are generated by shifts in customer demand and preferences), these trends are increasingly crossing the entire corporation to be felt down at the suppliers' level.

Products are becoming more and more complex (see the several examples presented in CHAPTER 2) and are beefed up with an increasing number of technologies. The ubiquity of technology development tools, the accelerating technology development cycle, the increasing number of technologies being introduced on the market, the increasing number of technologies relevant to any product… all these trends, coupled with customer demand for world class products with perfect quality and the lowest prices possible, are putting huge pressure on OEMs. In order to cope with these challenges, OEMs are keeping complexity of the value stream at their stage at the lowest level possible. Only technological systems that are relevant to the corporate strategy (systems that are relevant to the brand for example) are developed and integrated at the OEM level. Other technologies where economies of scale are becoming important are developed at the supplier level for different OEMs. Supply management functions at the OEMs are no more reduced to the definition of parts specifications and the negotiation of prices. Instead supply management is more and more taking on the responsibility of searching, scanning, and integrating technologies developed at the supplier level. In fact, we should stop speaking about supply management and start speaking about partnerships' management instead.

The objective of this chapter is to assess the requirements of suppliers and OEMs in their new roles and then propose policy recommendations that should be followed by companies in order to build successful partnerships with their suppliers. It should be noted that technology development partnerships are risky and sensitive because it is ultimately the entire competitive advantages of the company that are put at stake through these co-operations.

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[19] Adapted from Morgan L. Swink and Vincent A. Mabert, *Product Development Partnerships: Balancing the Needs of OEMs and Suppliers*, Business Horizons/ May-June 2000.

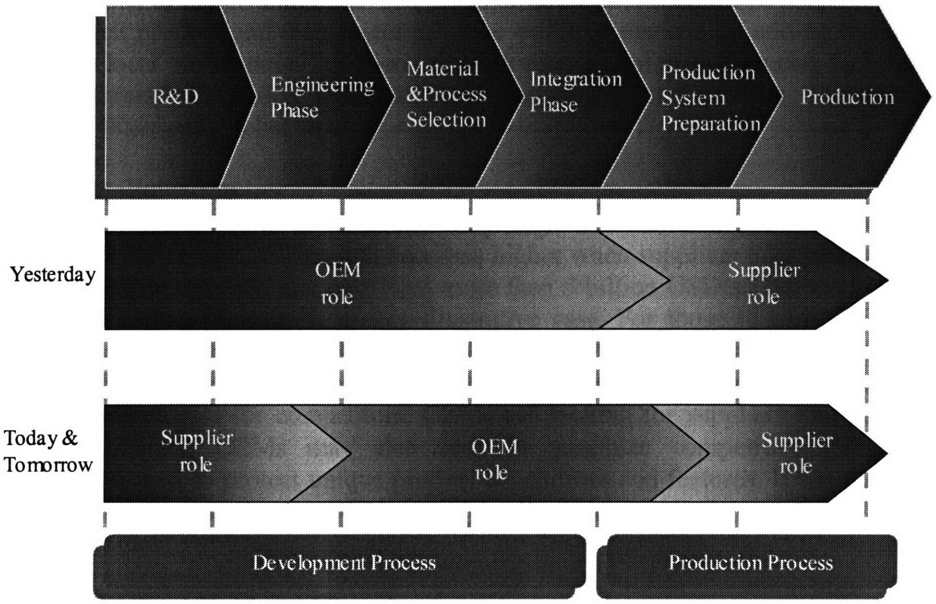

Figure 43: The Evolution of Suppliers' Role in the Development of New Technologies

2. CONFLICTING REQUIREMENTS AND MOTIVATIONS

A recently completed study survey in the automobile supplier industry revealed that (a) just over half of suppliers have a formal system of measuring customer satisfaction, (b) few go much beyond the functional quality, cost, delivery (QCD) measures and (c) virtually none make any attempt to benchmark themselves against their competitors[20]. This study shows the slow adaptation of suppliers to the new customer imperatives in a period where OEMs are in huge need for capable and helpful suppliers. This is why Japanese automakers consider only about a dozen of their 100-200 first-tier suppliers as "full partners". The rest are just suppliers that cannot be trusted with the company future and its intellectual capital. In this section, we will analyze the suppliers and the OEMs requirements from any OEM-Supplier relationship. The assessment of those requirements shows conflicting objectives, which is the source of many partnership issues.

2.1. The OEMs Needs and Requirements

The OEM requirements from suppliers can be summarized into three distinct categories: Requirements related to capabilities and competencies, requirements related to business strategy and finally requirements related to risk management.

2.1.1. Capabilities and Competencies

As described in the introduction, OEMs require suppliers to be more proactive in developing new technologies and providing ideas and solutions early in the fuzzy front end of the technology development process. In the Ford case that has been described in the previous chapter, Ford welcomes technologies that have been developed at the suppliers' level and certifies them to a concept ready level for future implementation.

2.1.2. Strategy Partnership

In several cases, suppliers have more knowledge about local markets than the OEMs. In these cases, and in addition to market expertise, they can provide capabilities and skills not available in a domestic market. Whirlpool provides a prime example for suppliers' global capabilities utilization with its deliberate efforts to establish a worldwide network supplying product R&D and Engineering skills. Suppliers in this network contribute to Whirlpool's global strategy by helping create and incorporate

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[20] Knibb Gormezano & Partners, Auto Briefing, June 2000.

features that appeal to the distinct needs and tastes of different markets. The purpose is to have a world platform for each product and then customize it to different markets by adding features and systems that respond to local preferences. Suppliers, through their global manufacturing facilities, produce the platform and, through their local expertise, build features for local markets. This approach responds successfully to Whirlpool global strategy.

2.1.3. Risk Minimization

The risk of new technologies is generally very high and has multiple aspects (design, market, integration, manufacturing…). This risk becomes higher when suppliers take part of the process. The sad example of Firestone tires that cost Ford more than 5 billion USD so far, excluding the damaged image and the pending lawsuits is a very illustrative case. For those reasons, OEMs are generally reluctant to allow suppliers to take the greatest responsibility in new technology development. More, the risk of confidentiality should be considered as well. Knowing that suppliers develop multiple and often-similar technologies for competitors, OEMs are looking for suppliers that can be trusted with their business secrets. OEMs may also seek to minimize competitive risks via exclusivity arrangements designed to protect unique product capabilities and features. If the supplier provides an innovative technology concept, the OEM may try to limit the supplier's use of it in other products for competitors.

2.2. The Suppliers' Needs and Requirements

Suppliers are trying hard to satisfy the increasingly demanding requirements of their customers. At the same time, they are asking for more support and reward from OEMs for their innovation and risk taking:

2.2.1. Reward for Up-front Involvement

Suppliers take important risks when developing new technologies, especially, when it is not in the case of an outsourcing agreement with an OEM. In order to reduce associated risks and get reward for their innovativeness, they look for early commitment of OEMs to long-term agreements or their up-front support through investments in training, equipment, or systems needed to integrate development efforts. For example, Xerox, the Stamford, Connecticut-based copier manufacturer, has an agreement with one of its suppliers, Schaffstall Manufacturing, in which Xerox guarantees future purchase of components as new models are ramped up for production, thus reducing Schaffstall's risk in preparing prototypes and tooling investments. Another more illustrative example is the one of Chrysler. To earn suppliers' trust and encourage them to invest in dedicated assets, Chrysler has given a growing number of suppliers' increasingly longer commitments. The average length of contracts held by a sample of 48 Chrysler suppliers in 1994 was 4.4 years. This average was 2.1 years in 1989 as shown by a study by Susan Helper titled "How Much Has Really Changed between US Automakers and their Suppliers?" (Sloan School of Management Review, Summer 1991).[21]

In mid 90's, Chrysler gave oral guarantees to more than 90% of its suppliers that they will have the business for the life of the model they are supplying and beyond if they satisfy a set of conditions that include cost and innovativeness. As a Chrysler executive expressed it: "The business is theirs to keep forever or until they elect to lose it". Suppliers, on the other side feel very comfortable with Chrysler as a customer, as expressed by one of them: "I would certainly say that we are more comfortable making investments and taking risks on behalf of Chrysler than on behalf of our other customers, with whom we have a less secure long-term future"[22]. This believe was of course before Chrysler merged with Daimler in 1998. After the disastrous merger, and because of cultural clashes, pressure from the Germans to deliver immediate savings and synergies and top talent departures from Chrysler, the merged group saw record losses in 2000. In a desperate reaction to save Chrysler from break-up, Daimler is now imposing huge pressure on suppliers to reduce their costs without helping them to achieve the savings targets. Although it is too early to predict the consequences of this strategy, signs

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[21] Dyer, J., How Chrysler Created an American Keiretsu, HBR, July-August 1996

[22] Dyer, J., *How Chrysler Created an American Keiretsu*, HBR, July-August 1996

show that suppliers are resisting pressure, which could, in turn, hurt trust and long-term relationships between them and Chrysler.

2.2.2. Confidentiality and Respect of Intellectual Property

Just as OEMs worry about their intellectual property and about the suppliers sharing their technologies with other competing OEMs, suppliers worry that their customers share their proprietary technologies with other competing suppliers. The motivation for OEMs to behave in a such way is to reduce the manufacturing cost by pushing suppliers to compete one against another. However, this behavior doesn't promote innovation because suppliers would lose the efforts and investments made in the technology development to other competing suppliers. Therefore, it is in the OEM interest, in order to encourage and benefit from suppliers innovation, to respect and reward their intellectual property. Moreover, suppliers greatly value OEMs that allow them to use what they learned from technology development to accommodate their other customers. This can be, in addition to this, in the OEMs interest, because a large business base for the suppliers minimizes the OEM long-term risk and reduces its purchasing prices.

2.2.3. Wealth Sharing with the OEMs

In addition to support and compensation for up front efforts, suppliers need motivation from OEMs for cost reduction and improvements in the technology. In the auto industry, a 50/50 sharing of the benefits from the improvement is common. However, some OEMs offer extra incentives for improvements. Chrysler offers incentives of up to $10 per car per pound of weight eliminated and $20,000 for each part eliminated which helps the suppliers and Chrysler as well offering the final customers performing cars.[23]

4. SOLUTIONS FOR TECHNOLOGY PARTNERSHIPS

In the above section, some of the issues that arise when considering partnerships between Suppliers and OEMs, in this section have been identified; we propose some of the solutions for suppliers' monitoring and technology supply management:

4.1. Sourcing or Not Sourcing

The first thing to decide when considering outsourcing partnerships is what subsystems will be indispensable to the company's competitive position over subsequent product generations. This choice will vary from company to company and ultimately drive companies' differentiation. In general, companies must first answer a number of questions before classifying subsystems. Subsystems should be classified as strategic when they:
(1) Have a high impact on what customers perceive as the most important product attributes (including cost)
(2) Require highly specialized design and manufacturing skills and specialized physical assets for which there are very few, if any, capable independent suppliers
(3) Involve technology that is relatively restrictive and in which there is a significant likelihood of gaining a clear technological lead.[24]

At this point, subsystems which are not strategic and for which technology concepts are known by all players and significant economies of scale can be seen at the suppliers level have to be outsourced.

For other subsystems that are deemed strategically important, more process-related questions must be answered to determine whether to develop or procure them:
(1) What are the supplier's engineering and manufacturing capabilities relative to the company's?
(2) What would it cost to catch up with the best suppliers, and can the company afford it?
(3) What is the structure of the subsystem supply market? Is it a low-margin competitive market or a high-margin monopolistic market?

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[23] Morgan L. Swink and Vincent A. Mabert, *Product Development Partnerships: Balancing the Needs of OEMs and Suppliers*, Business Horizons/ May-June 2000.
[24] Ravi Venkatesan, *Strategic Sourcing: To Make or Not to Make*, HBR November-December 1992.

Once these functionally strategic subsystems have been classified from a process point of view, the OEM faces one of the two following cases:

(1) If the subsystem is strategically important from a process point of view, than the OEM should develop its competencies in the field and aim for leadership when required investments can be justified. If they cannot, the OEM should look for partnerships to avoid being captive of a limited number of suppliers imposing their high margins on it.

(2) If the subsystem is not strategically important, than the company should exit the business on the long-term, but should focus, on the short term, on the investments already made to develop and manufacture the subsystem.

The following decision tree summarizes the analysis elaborated above:

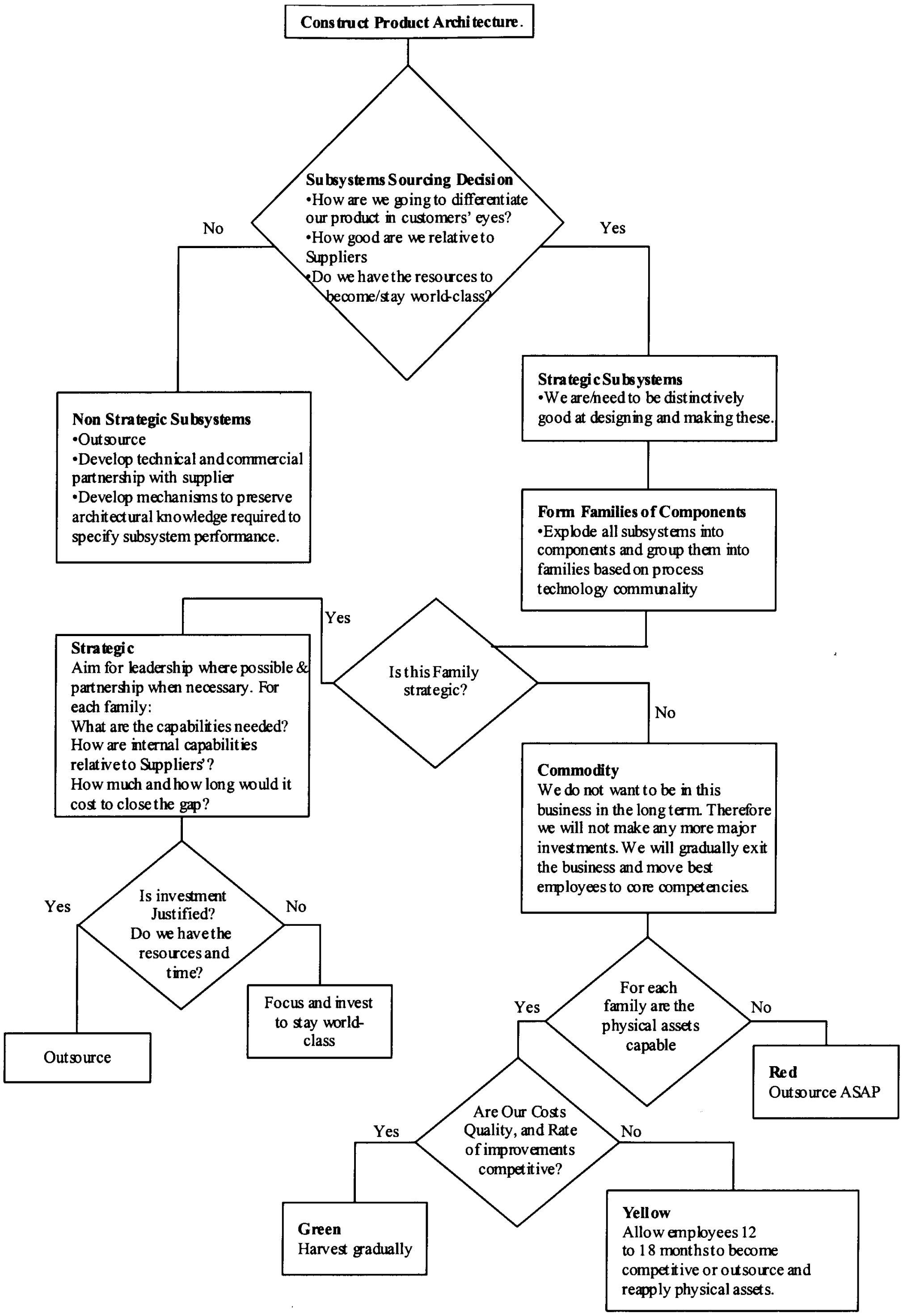

Figure 44: Outsourcing Decision Tree[25]

4.2. Communication is the Key

Communication between suppliers and OEMs is needed because of the technical complexity of the needs and the offerings of each player. Communication is also needed because of the number of departments involved in the development process. For example the marketing department has its own

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[25] Ravi Venkatesan, Strategic sourcing: To Make or Not To Make, HBR, November-December 1992

needs to be communicated to suppliers, manufacturing has its own needs to be communicated to suppliers, etc. The level and intensity of communication differs from one supplier to another and from one situation to another depending on the complexity of the subsystems being developed. In general, the levels of communications decrease with the maturity and experience of the supplier and increase with the complexity of the subsystems.

Kamath and Liker (1994)[26] classified suppliers into four types: Partner, Mature, Child, and Contractual (or Commodity) suppliers:
(1) Partners have their engineering capacities and have in general the same communication capacities and skills as the OEM itself.
(2) Mature Suppliers need only rough specifications as a base for starting the development work.
(3) Child Suppliers need complete and detailed specifications to commence work.
(4) Commodity Suppliers are those who make standard systems that can ordered from a catalogue.

Nellore, Soderquist, Siddall and Motwani (1999) have developed seven domains of focus for communication between a supplier and an OEM. According to the authors, problems and bad surprises that occur later in the development process are due, mainly, to the negligence of one or several of these domains:
(1) Product Requirements: describes the performances of the final product, its description as well as the means to arrive to it.
(2) Functionality: refers to the practical use of the product rather than technical details. Often partner suppliers are not given specifications at all; instead they are given the functionality of the system because they understand the implications of these functionalities.
(3) Process Requirements: In some cases, it is very important to agree on the processes and the manufacturing steps designed achieve the final product. For example, an OEM can impose that a particular test be performed on the final system.
(4) Standards: Legal standards, performance standards, country standards as well as any other OEM standards should be taken into consideration by the supplier. For example the OEM can forbid the supplier from using a particular set of materials. Knowing the standards reduces the risk of redesign and rework and prevents late changes. Partner and mature suppliers are supposed to know standards even if they are not clearly indicated by the OEMs.
(5) Drawings: In order to make explanations more explicit, drawings can provide a way to express details that can not be communicated orally or by writing. The need for drawings increases as the OEM moves toward dealing with child suppliers.
(6) Customer Requirements: When the OEM gives its requirements to its suppliers, it is in reality transferring the final user requirements to the suppliers. To avoid misinterpretations, the OEM should also communicate the original requirements. This can speed up the development process according to Smith & Reinertsen (1991).
(7) Level of Technology: Technology sophistication influences system behavior and its interaction with other sub-systems in the product. For this reason, it is important to communicate and mutually agree on the level of technology and the system interfaces. Again, the requirements precision increases when dealing with child Suppliers.[27]

4.3. Monitoring the Suppliers: The BMW Approach[28]

The above two sections underlined the importance of selecting the subsystems to be built in partnership (this point has been a center of interest in the Ford case study as well) and the importance of communication between the OEMs and the suppliers, in this section, a third critical success factor will be presented: Monitoring the suppliers. This factor will be presented in the particular case of BMW, which has been particularly successful in monitoring its suppliers.

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[26] Kamath, R., Liker, J., A second Look at Japanese Product Development, HBR, November-December 1994.
[27] Nellore, R., Soderquist, K., Siddall, G. and Motwani, J., *Specifications – Do We really Understand What They Mean?* Business Horizons/ November-December 1999.
[28] Wilhelm Becker, The Future of Purchasing –Supply Management as a Key Player and Value-engineering Task, Global Automotive Manufacturing & Technology Business Briefing.

Searching for Outside Innovations: This first step of the partnership process consists in the assessment of what can be developed by the suppliers. Due to the importance of this step, BMW has set up an Innovation Control Unit that systematically explores suppliers innovations and promotes worldwide co-operation with research establishments and universities of advanced education.

Once a promising innovation has been identified at a given supplier, the technology is assessed in terms of its adequacy with BMW priorities, which are: Road Dynamics, Safety, Convenience, Environment and Visual Appeal. In addition, supplier's history and references are assessed. If these assessments reveal that the supplier can be a potential provider of the technology, BMW moves to the following step of cooperation.

Next, a cooperation interface is put in place, the objective is to have an agreement between the OEM and the Supplier about the competencies that have to be dedicated to the project to foster cooperation and avoid overlapping activities and future surprises or differences of opinion.

Project Control: Issuing contracts for development to suppliers means scarifying responsibilities and having limited access to trade-offs and elements that have a direct influence on results (quality, costs, etc.) and the ability to deliver results. In order to minimize associated risk, BMW has developed a method that allows efficient project control. The various steps of this method are explicitly explained here bellow:

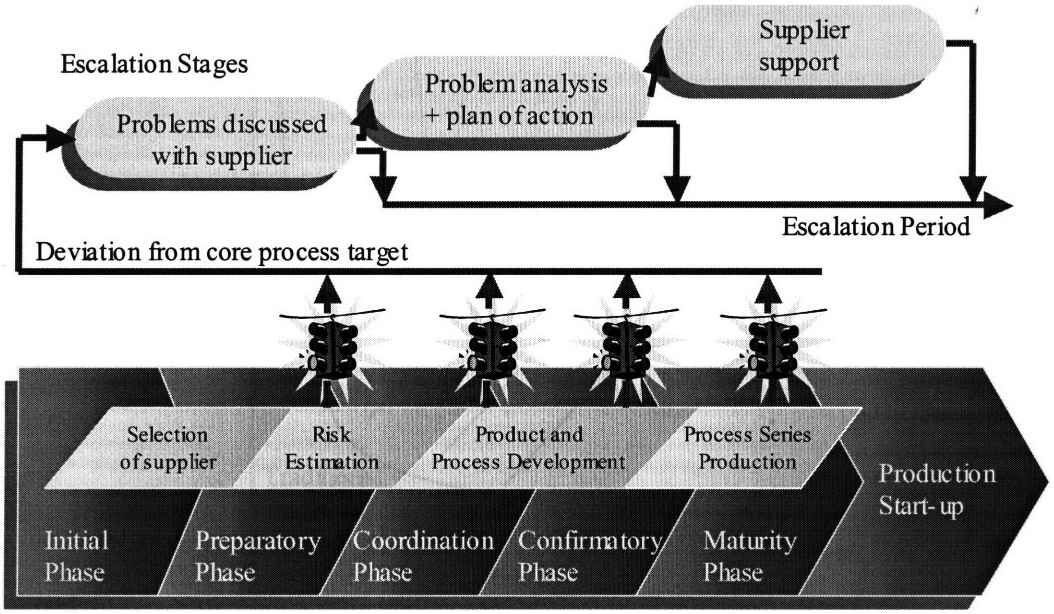

Figure 45: Control of Suppliers Projects Performance

As shown in figure 45, after the supplier selection, BMW conducts a risk assessment to make an initial determination of the intensity of supplier support required for the project. Repeated project-progress evaluation, followed by agreement on the necessary measures has the aim of ensuring that the agreed objectives are met. If the result is not up to the required standards, various measures are applied on an increasing degree. This escalation model comprises discussion of the problems, plans of action and finally supplier-support measures as a primary means of ensuring effective performance of the subsystem being developed.

5. TECHNOLOGY DEVELOPMENT ENABLED BY INFORMATION TECHNOLOGY

The irony of technology is that new technologies and new telecommunication advances such as the Internet are changing the way technologies are developed. This is not surprising since the development of technology is simply the art of transforming information.

Several publications describe how the Internet is changing the traditional economics of information. One strategy, described by Evans and Wurster, authors of the Book "Blown to Bits"[29] is to separate the information-rich part of the business from its material support, this offers limitless possibilities for information manipulation. In order to support this strategy, they define the traditional trade-off between richness and reach of information. Reach simply means the number of people, at home or at work, inside a company or between different companies, exchanging information. Three aspects of the information define richness: The first is bandwidth, or the amount of information that can be moved from sender to receiver in a given period of time. The second aspect is the degree to which the information can be customized. The third aspect is interactivity. Dialogue is possible for a small group, but to reach millions of people the message is monologue. In general, the communication is rich if information has required proximity and dedicated channels whose costs or physical constraints have limited the size of the audience to which the information could be sent. Conversely, the communication of information to a large audience has required compromises in bandwidth, customization, and interactivity. Figure 46 shows the impact of Internet of the reach and richness of information.

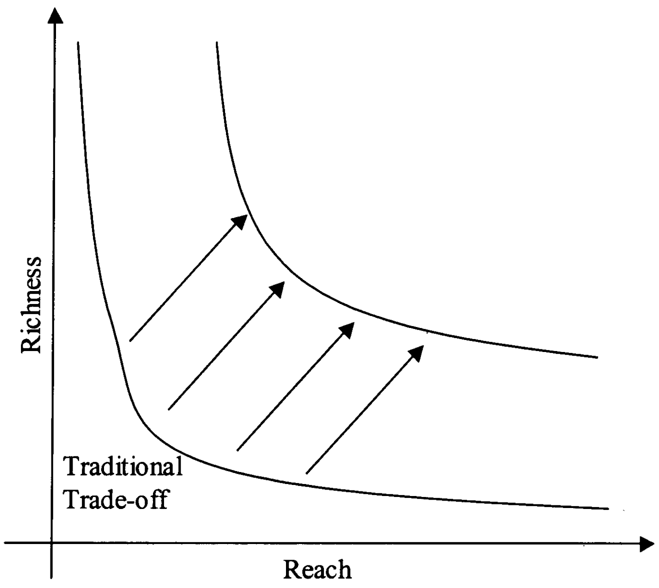

Figure 46: The Impact of Internet on Traditional Information Trade-offs

The Internet shifts the Rich/Richness curve outwards and eliminates the traditional trade-off between Rich and Richness. More people have access to richer information that flows seamlessly.
The companies that have gone the furthest in their usage of the Internet claim to save astonishing amounts, especially in transaction costs. GE plans to cut 15% from its annual base cost of $100 billion in both 2001 and 2002. That is five times the typical annual growth in productivity, even for a fast moving firm, of 3-4%. In addition, the company hopes to reduce the prices of materials it purchases through electronic auctions to make additional savings of about $2 billion.[30]

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[29] Philip Evans, Thomas Wurster, Blown to bits: How new economics of information transforms Strategy, Harvard Business Press, 1999.

[30] The Economist, E-Management Survey November 2000

If the benefits of Internet are recognized and seem to be accepted by the majority of companies, the benefits brought by the Internet to OEMs-suppliers relations are not immediate and especially in the field of cooperation for technology development:

5.1. Positive Impacts

The importance of information technology has been highlighted in the Ford case study. In comparison with other corporations, Ford made astonishing progress in this field during the past years. It launched its public Internet site in mid-1995; by mid-1997 the number of visits to the site had reached more than 1 million per day. A company-wide intranet was launched in mid-1996, and by January of 1997, Ford had in place a Business-to-Business (B2B) capability through which the intranet could be extended in a secure manner beyond company boundaries into an extranet, potentially connecting Ford with its suppliers. Ford teamed with Chrysler and General Motors to work on the automotive Network Exchange (ANX), which aimed to create consistency in technology standards and processes in the supplier network, so that suppliers would not have to manage different means of interaction with each automaker. Today, Ford has the world largest intranet with 170,000 employees connected worldwide and is largely enjoying the fruits of its investment strategy with a very integrated value chain that translated in cost reduction and record profits ($6.9 billion in 1998 and the US industry lead in profit per vehicle of $1,770).

Technology can be employed to overcome the constraints usually imposed by geography on information flow. Teams on different continents need to be able to work together as if they were in the same building. The Internet definitely provides the means to do this. With regard to the suppliers, the Internet allows sharing of information between the supplier and the OEM. Engineers from the two companies can work as if they were in a unique virtual team. Sharing past experiences (which allows avoidance of the 'reinvent the wheel' phenomenon) as well preparation of resources for just-in-time processes would be possible through available information. This will inevitably reduce time to market as well as development cost. On the other side, the creation of virtual cross-functional teams ensures coordination in designing and engineering the subsystem and prevents costly and resource-consuming redesigns and reworks. Finally, using the Internet, the integration phase would be a routine step inside the overall process, since more of the integration work would have been done upfront.

From a control point of view, the Internet allows real-time monitoring of suppliers to avoid bad surprises. Suppliers can inform OEMs about tests, verifications and approvals. If problems occur, they are identified immediately and support procedures are launched in real time.

5.2. Negative Impacts

The Internet offers the opportunity for OEMs to reach an unlimited number of suppliers through a simple click creating, thus, price transparency and putting pressure on suppliers to reduce their cost. While cost cutting is a good thing in itself, the way it is done is an issue. By creating electronic auction systems, OEMs don't try to understand each supplier's constraints and can't measure the other performances that a supplier can deliver and that cannot be measured quantitatively through the auction system. The following table summarizes the negative impacts created by an Internet-only relationship in comparison of what can be done offline:

Offline World	Online Exchange
Recognition of past performance and track record (relationship orientation)	Little recognition or Credit for past performance (transaction oriented)
Recognition of suppliers' need to make a fair profit	No responsibility for suppliers' profit margins
Feedback from suppliers encouraged	Little support for feedback from suppliers
Expectation of business relationships beyond contract	No guarantee of business relationship beyond the contract
Considerable performance expectations beyond the contract	No performance expectations beyond the contract
Cooperative and trusting positive-sum game	Adversarial, zero-sum game

Figure 47: Negative Effect of Online Contract Award

It should be highlighted, at this stage, that all the negative impacts occur at a business level, while the positive impacts take place at a technical and organizational level. This brings us back to CHAPTER 5 and Thomas Johnson's philosophy. It is not by imposing performance targets on management that they will be met, instead, it is by understanding the organization and working at the operational level that performance objectives will be met. Also, negatives impacts occur at the initial phases of the cooperation process, where the entire long-term relationship between the OEM and its suppliers is put at stake because of performance-related selection criteria. On the other side, positive impacts occur during the cooperation process itself, where by using the Internet, communication can be enriched, development time reduced, cost reduced and mistakes identified early. Managers should be very careful to these effects, because, at the end of day, the Internet can't evaluate the intangibles of the OEM cooperation with its suppliers. The best poof of this issue is perhaps the fact that in Japan there are no parts exchanges such as Covisint in the US. Japanese automakers, afraid of destroying their relations with their suppliers, (relations that were built over a long period of time since the end of World War II) resisted such structures. Finally, it should be noted, that these auction systems have been used so far only for parts, but nothing will prevent the OEMs from fixing the specifications of the systems they need to a fair amount of detail and ask suppliers to bid electronically for the development of the systems in question.

6. SUMMARY

In this chapter, we first introduced the global trends in the OEMs-suppliers relationships and then studied the requirements of both the OEMs and the suppliers. Unsurprisingly, these requirements are in contradiction and generate issues in cooperation and long-term relations between the OEMs and their suppliers. After addressing these issues, we presented a road map for successful decision-making in the field of technological subsystems outsourcing. The example of BMW shows that monitoring suppliers and providing them support are critical success factors. Finally, the role of new technologies such as the Internet on the OEMs-suppliers cooperation was assessed. Although such tools are widely accepted as cost-cutters, their effects on long-term cooperation are far from obvious and can be negative in some cases.

CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

This chapter reviews the research documented in this thesis. It first provides a brief discussion of research objectives, key questions and research methodology. It then summarizes major findings and discusses directions for future related research.

1. REVIEW OF RESEARCH OBJECTIVES, KEY QUESTIONS, AND RESEARCH METHODOLOGY

In the introduction chapter, it has been set as a research objective to find to what extent Lean can be an enabler for technology corporate objectives. The entire thesis shows that this question is far from obvious when attempting to understand all the challenges of technology and their implications on the organization. This thesis concentrated on the interactions between contemporary technology trends and lean technology development. Basing our arguments on a study made by Professor Roberts from Sloan School of Management (Founder of the Management of Technology Program) on global technology trends, CHAPTER 2 presented five main technology trends that are determining the success and failure of companies. CHAPTER 3 described the axiomatic design methodology, a logical framework that was used in CHAPTER 4 to link high level technology imperatives to the operational solutions designed achieve them. CHAPTER 5 showed that lean technology development could effectively lead to the achievement of technology imperatives but needs to be complemented with a broad technology strategy vision. CHAPTER 6 saw an application of the frameworks developed in earlier chapters to a real world case study. Finally, CHAPTER 7 looked to the critical role of suppliers in technology development and the broader issue of managing the company knowledge and its use of emerging information technologies.

2. SUMMARY OF MAJOR FINDINGS

2.1. A Challenging World

CHAPTER 2 described the increasingly challenging issues of technology as a way for creating sustainable competitive advantage. Five trends were analyzed. The ubiquity of technology tools, the proliferation of technologies relevant to any product, the emergence of a multitude of process-related technologies, the increase of technologies introductions and the decrease in technology development cycle time are all trends that are making the use of technology as a competitive weapon a more difficult strategy than what it used to be. In fact, the success and failure of companies depends on their abilities to have a systematic process for technology development management and not on the complexity of the technologies they are developing.

2.2. A Technology Decomposition and a Lean Engineering Framework

In CHAPTER 4, a technology decomposition that links the strategic objectives of technology management to the underlying operational solutions was developed. This decomposition tries, in fact, to answer the main question of the thesis using a logical approach (axiomatic design). Then, the Lean Engineering Framework was presented and mapped onto the Technology Decomposition. The mapping shows that when some complementary considerations are added to the Lean Engineering Framework, such as questions related to the definition of a technology strategy, it does respond to technology management imperatives and allows maximization of value for all stakeholders of the corporation.

2.3. Applications to Real World Situations

In CHAPTER 6, the frameworks developed or discussed in earlier chapters were applied to a real world situation: Technology development at Ford. The study identified areas of improvement and made recommendations to achieve a leaner technology development process. From a pedagogical point of view, the underlying research shows to what extent theoretical frameworks can be helpful in resolving real world problems and creating value for corporations. This, in itself, underlines the importance of continuing research in the field of technology development and the importance of doing it in close collaboration and coordination with industries to avoid deviating from real world problems.

2.4. Suppliers Policy Issues

CHAPTER 7 analyzed the challenges of supplier relationship management. Indeed the requirements of suppliers and OEMs are generally contradictory, which lead to situations of conflict and generate multiple issues when considering partnerships. After the study of the objectives of each of the partners, solutions for effective co-operation have been developed. This includes a strategic selection of systems to be built in partnership, communication and monitoring. Finally we have researched how information technology is affecting technology development and OEMs-Suppliers relationship. We have shown, in particular, that not all the impacts are positive, instead some impacts destroy one of the main critical success factors: Trust.

3. SUGGESTIONS FOR FURTHER RESEARCH

Although we have tried to answer the maximum number of questions in this thesis, every answer generated new questions. This is by definition research. However it is time to conclude this thesis in the same way it began in the introduction: Questions.

Based on the findings of the thesis, the following subjects of research should constitute a natural follow up:

3.1. Evidence for Lean as Enabler for the Achievement of Technology Imperatives

So far the evidence that has been presented in this thesis to show how corporate technology objectives can be achieved through the application of Lean Principles has been theoretical through logical analysis. The case study presented in CHAPTER 6 is another evidence that Lean Principles can lead effectively to a better technology management. However, in order to understand completely the implications of technology from a strategic point of view further case studies and further evidences from the corporate world are needed. For more effectiveness, it is advised that the studies would include not only Lean success stories but failures as well in order to understand critical risk factors.

3.2. Completion of the Technology Decomposition

At this point, the Technology Decomposition goes down to only three levels (three levels of FR-DP pairs). At the lowest level of the decomposition, the DPs are still too abstract to be applied directly. The lower-level pairs should be decomposed further down (at least two additional levels down) to arrive to acceptable details for implementation. This work has not been done in the thesis because it wasn't the purpose. The purpose here was to see to what extent Lean Principles could be the solution for technology imperatives. The finalization of the decomposition will allow for a complete tool that can be used to assist managers in designing their companies' technology development organizations and putting adequate technology processes and procedures in place.

3.3. Value Creation in Technology Development

Although huge progress has been made in the definition of technology development value, this work is still largely unfinished. The majority of definitions have been based on a complete analogy with manufacturing. This analogy, though elegant, has many drawbacks and doesn't completely capture the complexity of information transformation when developing a technology. In addition, the issue of technology value, not being realized unless the technology is integrated, manufactured and commercialized, has not been completely addressed. What needs to be done at this point is a wider reflexion about technology value. Can't the classical manufacturing approach to value be avoided and a more generic approach created?

3.4. The Role of Suppliers

In CHAPTER 7, the role of suppliers in the development of new technologies has been identified, then the conflictual nature between the requirements of the suppliers and those of the OEMs was discussed and finally some partnership critical success factors such as wise selection of systems to be outsourced, communication and monitoring were presented. However, this should be seen as only the beginning of a much wider reflexion about the role of suppliers and the management of supply in general. 'How will suppliers' concentration affect the OEM-Supplier relationship on one hand and the suppliers' ability to respond to OEMs requirements on the other hand?' 'How will this affect their innovativeness?' 'How can the Internet be used to impacts positively the OEM-supplier relationship?' All these are questions that need to be assessed and studied further in detail in future research.

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APPENDIX: TENCHNOLOGY DECOMPOSITION