The effects of part commonality on product development lead time.

by

Nicholas Svensson

B.Sc. in Applied Physics (1989)

University of Waterloo

Submitted to the System Design and Management Program
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Signature of Author...
Nicholas Svensson
System Design and Management Program
January 2005

Certified by ....
Thomas Roemer
The Robert N. Noyce Assistant Professor of Management
Thesis Supervisor

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ABSTRACT

Nortel Networks, a leading global supplier of telecommunications equipment, is engaged in an increasingly competitive global market place. Within this market, Nortel Networks is positioning itself as the leader of global network transformation. The vision of the new transformed network is one in which disparate network elements are converged onto single architectural platforms serving the Client, Wireless Access, Network Services, Multi-services Packet, VoIP, Multi-services Optical and Element Management aspects of the newly transformed network architecture.

This paper focuses specifically on the hardware development process associated with the CDMA wireless access element referred to as a base transceiver station (BTS) in the transformed network. The effect of part commonality on product development lead times are investigated at four levels of integration: common part (ASIC), common assembly (circuit pack), common field replaceable unit (module) and finally the common platform (BTS).

At increasing levels of integration, the use of common parts leads to longer product development lead times. This observation is examined using two methodologies.

The first methodology utilizes the three lenses framework focusing primarily on the impacts of organizational structure on the product development process. An evaluation of the existing barriers preventing joint gains and acceptable compromises to be achieved amongst share holders in joint development programs is discussed. Methods by which to minimize the impact of organizational structure on common product development lead time are given and comparisons are made with alternate organizational models from within the telecommunications industry.

The second methodology employed utilizes task based design structure matrices (DSM) to analyze the implication of part commonality on product development lead times for projects structured in accordance with the Nortel Networks Life Cycle Management model. Effects modeled include stochastic durations, probabilistic iterations, learning effects, resource constraints, parallel tasks and overlapping tasks. An evaluation of the results indicates an increased sensitivity to extended product development lead times associated with probabilistic

iterations. This is shown to be particularly evident during the requirements definition phase in which multiple stakeholder requirements must be captured comprehensively. This sensitivity is amplified by the fact that product verification takes place in multiple labs each exercising the equipment in unique and un-accounted for configurations.

Based on the above analysis, a framework to ascertain the optimum level of commonality to pursue on a given product is given.

BIOGRAPHY

Nicholas Svensson is a senior manager at Nortel Networks, a leading global telecommunications equipment supplier. He has held several positions within the company over the last five years, including Test Engineering Manager, Supply Chain Operations Manager and New Product Introduction Manager. These positions were in the operations division of Nortel Networks and were directly linked to the Code Division Multiple Access (CDMA) wireless infrastructure product line. Nicholas is a graduate of the University of Waterloo (1989, Bachelor of Science in Honours Applied Physics).

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"Wisdom is the principle thing, therefore get wisdom; and with all thy getting, get understanding." –Proverbs 4:7

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3-DCE	3-Dimensional Concurrent Engineering
3G	Third Generation
AEAP	As Early As Possible
ANA	Analysis
ASIC	Application Specific Integrated Circuit
ATM	Asynchronous Transfer Mode
BDP	Business Decision Point
BTS	Base Transceiver System
CDMA	Code Division Multiple Access
CF	Common Features
CPA	Component Placement Agreement
CRM	Common Radio Module
CS	Circuit Schematic
CuR	Customer Ready
DAC	Digital to Analog Converter
DC	Design Close
DE	Design Estimate
DFM	Design For Manufacturability
DI	Internal Design Review
DR	Design Review
DS	Detailed Specification
DSM	Design Structure Matrix
DSP	Digital Signal Processing
DT	Designer Test
DTRx	Digital Transmit Receive
DVT	Designer Verification Testing
FA	Functional Agreement
FPGA	Field Programmable Gate Array
FRU	Field Replaceable Unit
GM	General Manager
GO	Global Operations
GPSTM	Global Positioning System Timing Module
GS	General Specification
GSM	Global System Mobile
HSSL	High Speed Serial Link
HSSPCII	High Speed Serial Protocol – II
IF	Intermediate Frequency
IP	Internet Protocol
IPT	Integrated Product Team
IPTL	Integrated Product Team Leader
ISDN	Integrated Services Digital Network
KIL	Key Items List
MSL	Manufacturing Stock List
NRE	Non Recurring Engineering
OBSAI	Open Base Station Architecture Initiative
OEM	Original Equipment Manufacturer
OPM	Object Process Methodology
PA	Physical Agreement
PDM	Product Development Manager
PLM	Product Line Management
PLMN	Public Land Mobile Network
PMT	Portfolio Management Team
PPR	Peak Power Ratio
PSPDN	Packet Switched Public Data Network
PSTN	Public Switched Telephone Network
RF	Radio Frequency
Rx	Receive
SDS	System Design Specification
SF	Specific Features
SS7	Signaling System Number 7
T1IM	T1 Interface Module
TCP	Transfer Control Protocol
TRM	Transmit Receive Module
TRx	Transmit Receive
TTC	Time to Cost
TTM	Time to Market
TTQ	Time to Quality
Tx	Transmit
UMTS	Universal Mobile Telephone System
VP/R	Verification Plan/Report
W-CDMA	Wideband-CDMA
WTL	Wireless Technology Lab

1 INTRODUCTION

1.1 Insight from a Brief History of Product Development

The sole purpose of new product development is to satisfy an existing market or customer need. According to Philip Kottler, it is possible to "distinguish among five types of needs: stated needs, real needs, unstated needs, delight needs and secret needs"[1]. Each need types may drive a unique product development strategy or approach but in every case minimizing the product development cycle time is of benefit to the developer. Product development cycle time is therefore a competitive measure not in absolute terms but in relative terms when measured with respect to the product development cycle times of the other competing parties. Metaphorically this can be thought of as the squirrel wheel of progress.

The need for and pursuit of shorter and more predictable product development lead times is well documented in literature. Although typically thought of as a modern problem, product developers have for centuries struggled against fierce competition in bringing a new product to market. Some brief examples are given below.

The Longitude Act passed by the British Parliament on July 8, 1714 was in essence the translation of a real need into a stated need. A prize of £20,000 was given to the first individual who could solve the dilemma of estimating longitude to within half a degree whilst at sea. The need was great as was the prize; the competition was open to any person of any nationality using any method. The real need could not be overstated. In a single incident on October 22, 1707,

[1] Kottler, Philip, 2003,"A Framework for Marketing Management", 2nd Ed., Prentice Hall, Upper Saddle River, New Jersey, ISBN 0-13-100117-5

two thousand sailors lost their lives and four British warships were sunk as they ran a ground off of the shores of the Scilly Isles significantly off course. In 1727, John Harrison began in earnest to develop a precision chronometer capable of winning the £20,000 prize. To win the prize, the chronometer would have to be accurate enough to allow the determination of longitude to within half a degree after completing a voyage from England to the West Indies[2]. Before claiming the prize in 1774, a full forty seven years later, five iterations of the chronometers had been built (H-1 through H-5). Of note throughout the process, keen competition, sabotage and even politics played a role in determining the ultimate winner of the prize.

Responding to an unstated need in the late 1860's, Thomas Edison developed the world's first stock ticker. By 1876, Thomas Edison had opened the worlds first corporate research center at Menlo Park, New Jersey[3]. The sole purpose of the Invention Factory was to develop new and commercially viable technologies as quickly as possible to meet the unstated and delight needs of the world market. The phonograph is an excellent example of a product developed at Menlo Park which met a delight need. All required materials, people and machinery were assembled on site. This included 40 trained mechanics and technicians, chemicals, laboratory instruments, electrical testing devices as well as a fully equipped machine shop. The Menlo Park research centre had been in existence for two years before work began in earnest on the incandescent light bulb. By the time Thomas Edison decided to join the race to develop the first commercially viable incandescent light bulb, Joseph W. Swan[4] from England had a seventeen year head start. Leveraging the benefits of a focused, cross functional and co-located team, Thomas Edison was

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[2] Sobel, Dava, 1995, "Longitude", Walker and Company, New York, ISBN 0-8027-1312-2, pp80-83
[3] Utterback, James, 1996, "Mastering the Dynamics of Innovation", Harvard Business School Press, Boston, Massachusetts, ISBN 0-87584-740-4, pp 59-60
[4] ibid

able to gain the technical lead in incandescent light bulbs within twelve months. The now well known quote from Thomas Edison that *"Genius is one percent inspiration and ninety-nine percent perspiration"* is an indication of the unpredictable and consequently iterative nature of product development. The competition for this new market in incandescent light bulbs was fierce with eight competing companies participating[3].

In response to the stated needs of the Unites States government near the end of World War II, Kelly Johnson of Lockheed Martin introduced the "Skunk Works" model of product development. This model of product development was specifically focused on delivering quantum leaps in technology for aerospace systems in very short time spans[5]. By co-locating the project teams and removing external distractions, efficient communications were achieved. Also, a key difference between the "Skunk Works" model and traditional phase gate models in use at the time was that the team was allowed to tailor the existing development processes to efficiently meet their project objectives. "Getting your hands dirty" was the modus operandi.

Of the fourteen basic operating rules of the Lockheed Martin *"Skunk Works"* model, those of general applicability to industries outside of aerospace are single point of program control, where the project team consists of only the most essential employees each with a high degree of expertise, use a simple flexible configuration management systems and minimize the requirement for external reports whilst recording important work thoroughly.

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[5] Forsberg, Kevin, Hal Mooz and Howard Cotterman, 2000, "Visualizing Project Management", 2nd Ed , Wiley and Sons Inc., New York, ISBN 0-471-35760-X

By the late 1980's the Japanese had gained a reputation for being able to bring a myriad of new and innovative products to market more quickly than anyone else. This was a complete shift from a few decades before. Along with this apparent lead in product development, their manufacturing sector was also strong whereas the American manufacturing sector was in a general decline. Several key benchmark studies were carried out primarily in the automotive industry by Womack, Jones and Roos[6]. These studies highlighted the need and benefit of "Lean Manufacturing" and "Concurrent Engineering"[7,8]. The traditional phase gate "over the wall" product development process was no longer sufficient to meet the shorter cycle times required to stay competitive through the 1980-90's. The benefit of concurrent engineering within the automotive industry was definitively demonstrated by Clark and Fujimoto[6] in 1987. Using a sample of twenty nine "clean sheet" new vehicle development programs between, 1983 and 1987, they found those using concurrent engineering practices on average took 1.7 million hours of effort and 46 months to complete whereas those who did not use concurrent engineering practices took on average 3 million hours of effort and 60 months to complete. Product design for manufacturing and assembly became the new benchmark of product development processes through the 1990's. Design for manufacturability guidelines provided by Boothroyd, Dewhurst[9] and others were a major influence in reshaping traditional product development processes into concurrent product development processes. Once again, shorter product development cycle times were required to remain competitive.

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[6] Womack, James, Daniel T. Jones and Daniel Roos, 1990, "The Machine That Changed the World", MIT Press, Cambridge, Massachusetts, ISBN 0-06-097417-6, pp 104-137

[7] Fine, Charles, 1998, "Clock Speed", Purseus Books, Reading, Massachusetts, ISBN 0-7382-0001-8

[8] Lean manufacturing is a method by which only the absolute minimal material required to finish a product is available at any one time in the factory, Concurrent engineering is the act of including design for manufacturing (DFM) feedback into the design process at the very earliest stages of product development hence shortening the overall development cycle.

[9] Boothroyd, Geoffrey, Peter Dewhurst and Winston Knight, 2002, "Product Design for Manufacture and Assembly", 2nd Ed., Marcel Dekker Inc., New York, ISBN 0-8247-0584-X

By the mid to late 1990's, three major concepts emerged. The first concept was the dominant design. A dominant design is defined as *"the design within a product class that wins the allegiance of the marketplace, the one that the competitors and innovators must adhere to if they hope to command a significant market following"*[10]. A dominant design is typically not the first to market but is defined through a process of consolidation within an industry. The IBM PC is an example of a dominant design; it was neither first to market, superior in performance or price.

The second major concept was disruptive technology and the evolution of industries. In the book *"The Innovators Dilemma"*, Christiansen demonstrates that even well managed companies that do everything correctly can fail. Using the metaphor that coping with the relentless onslaught of technological change was akin to scrambling up a mudslide Christensen writes *"Clearly, the leaders in this industry did not fail because they became passive, arrogant, or risk-averse or because they couldn't keep up with the stunning rate of technological change. My technology mudslide hypothesis wasn't correct."*[11]. As defined by Christensen, a disruptive technology is a technology that originally only serves the lower end of a market but through continuous technological advances ultimately displaces the incumbent technology. This can be particularly damaging to established firms as outlined by Henderson and Clarke in their study of the photolithographic alignment equipment industry, *"Our analysis of the industry's history*

[10] Utterback, James, 1996, "Mastering the Dynamics of Innovation", Harvard Business School Press, Boston, Massachusetts, ISBN 0-87584-740-4,pp 24-26
[11] Christensen, Clayton, 1997,"The Innovators Dilemma", Harper Business Press, New York, ISBN 0-06-662069-4

suggests that a reliance on architectural knowledge derived from experience with the previous generation blinded the incumbent firms to critical aspects of the new technology" [12].

The third concept, called 3-D concurrent engineering[13] (3-DCE), was introduced by Charles Fine (1998) in his book *"Clock Speed"*. The concept extols the necessity to not only consider the product and its manufacturability but also to consider the complete supply chain. Charles Fine also recognized that not all industries evolve at the same pace. In order to understand the differences, he coined the term clock speed as a measure of how frequently new products are introduced to the market within a given industry. In the case of the Aerospace industry, companies like Boeing, introduce new products once or twice a decade whereas companies in the Infotainment industry, such as Disney, seek to launch a new motion picture once a year.[14] Therefore by applying Charles Fine's definition of clock speed, one can say that the Aerospace industry has a much slower clock speed than the Infotainment industry.

Obviously, long term success is not defined by the quick introduction of a single product or idea but rather an evolving product portfolio which targets the continuously changing needs of the customer. Sighting examples from Hewlett-Packard, EMC, Black & Decker and Boeing Meyer and Lehnerd[15] describe the benefits of commonality, standardization, compatibility and choice of product platforms in *"enabling companies to design technologically superior products more easily"*[16]. Therefore, decisions on the degree of commonality, standardization,

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[12] Henderson, Rebecca and Kim Clark, 1990, "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms", Administrative Science Quarterly, 35 (1990): p 24
[13] Fine, Charles, 1998, "Clock Speed", Purseus Books, Reading, Massachusetts, ISBN 0-7382-0001-8, pp 3-15.
[14] ibid
[15] Meyer, Marc, H, Alvin P. Lehnerd, 1997, "The Power of Product Platforms", The Free Press, New York, ISBN 0-684-82580-5, p 1
[16] ibid

modularization and choice of platforms are critical to the long term success of an organization. Unfortunately, driving commonality across multiple product's and platforms during a product development cycle is very complex. Unlike re-use[17], commonality requires interaction at each stage of the design process amongst many stakeholders on parts whose features, functions and physical attributes are in many cases still being defined. This added level of complexity adds significant communications cost and lead time to the product development process, typically conflicting with the short term business objectives.

In retrospect, the ongoing need to continually reduce product development lead times inevitably leads to a more integrated, concurrent and consequently complex[18] product development environment. One in which the communication of information between individuals is of paramount importance. As the number of stakeholders increases, within a product development team, so does the need to communicate. The maximum number of pair wise communications within a development team can be calculated using the relation $\frac{n \cdot (n-1)}{2}$, where n represents the number of individual stakeholders. Commonality offers a possible solution to this dilemma by simplifying the end state but this can only be achieved after investing in added development time and cost up front.

In an effort to reduce future product development lead times and cost, many organizations are faced with the dilemma of having to invest in extended product development lead times in the short term due to the implementation of a commonality strategy. In fast clock

[17] In this context re-use refers to the choice of one product design team to utilize an already developed part typically the desired state after the execution of a successful commonality strategy.
[18] In this context complexity refers to the relative number of persons required to deliver a competitive solution to the market in time.

speed industries where the dominant design has not yet emerged or a new disruptive technology is on the horizon this may not be an obvious decision. Also, architecturally committing oneself to a single architecture which may or may not be able to utilize new and developing technologies may in the long term be of more detriment than benefit.

1.2 Scope and Focus of Paper

This paper focuses specifically on the hardware development process associated with the code division multiple access (CDMA) wireless access element commonly referred to as a base transceiver station (BTS). The impact of imposing commonality constraints on new product development lead time is investigated at four levels of integration; common part (ASIC), common assembly (circuit pack), common field replaceable unit (module) and finally the common platform (BTS).

The objective of the paper is to provide a general framework by which the implication of a chosen commonality strategy when applied to similar telecommunications equipment can be assessed a priori with respect to its impact on product development lead time. This paper is not intended to define the optimum degree of commonality to pursue on a CDMA BTS nor necessarily the best way to achieve the commonality strategy chosen.

The main interest in studying this particular industry is that it has several unique attributes not commonly found elsewhere. The first is that the wireless segment of the telecommunications industry has a particularly fast clock speed. One that has outstripped the current product development lead time of most of the major incumbents. This makes product portfolio planning very challenging and uncertain. The second attribute is the split in development effort between the hardware platform and the software that runs on it. In this industry, only 30% of the design effort is focused on new hardware whilst the balance is reserved for software development. However, one cannot have common software unless one first has common hardware. The final attribute is the emergence of a dominant technology which will ultimately lead to the convergence of several existing platforms within the industry.

1.3 Setting of Study

The data used for analysis in this paper was provided by Nortel Networks and reflects work done in the period between 2000 and 2003 within the Wireless Networks line of business. During this period, the company had four distinct lines of business namely Enterprise Networks, Optical Networks, Wireline Networks and Wireless Networks. A brief corporate history with an emphasis on the evolution of the Wireless Networks line of business is provided for context.

1.3.1 Nortel Networks Transition into Wireless Networks

Nortel Networks is a Canadian based telecommunications OEM with a long history of innovation and growth[19]. The company grew from humble beginnings in 1882 as the telephone set manufacturing department of the Bell Telephone Company of Canada. By the late 1980's, Nortel Networks had established itself as the dominant global supplier of digital switching equipment with its trademark DMS line of digital switches. Looking to expand into new market

[19] A more detailed chronology of Nortel Networks corporate history can be found in Appendix 2.

areas the company entered the Wireless Networks business in 1992 through acquisition, alliances and internal investment.

The move into the Wireless Networking business began with the acquisition of the cellular systems business from NovAtel[20] which at the time was a joint venture between two regulated utilities within the province of Alberta, Canada. As part of the deal, Nortel Networks also agreed to invest $12 M in a Calgary based centre of excellence to which 225 NovAtel employees were transferred[21]. This acquisition allowed Nortel Networks rapid entry to the AMPS/TDMA wireless market within North America. This was quickly followed by a strategic alliance with Matra Communications S.A. of France, enabling access to the fast growing GSM wireless market in Europe. This strategic alliance ultimately resulted in the complete acquisition of the Matra Communications GSM business by Nortel Networks including all assets and employees[22]. Also in 1992, the company established its new wireless headquarters in Richardson, Texas. By the end of 1992, Nortel Networks had entered the Wireless Network business.

1.3.2 Wireless Networks Organizational Structure 2000-2003

For the periods of interest to this paper, the Wireless Networks Access business had the functional organizational structure represented in Figure 1 - Figure 4 for the period of 1999-2003.

[20] Cooper H. Langford, Jaime R. Wood and Terry Ross, 2002, "Origins and Structure of the Calgary Wireless Cluster", Faculty of Communication and Culture Working Paper, University of Calgary.
[21] Ibid, NovAtel Communications was a joint venture between two regulated utilities, Alberta Government Telephone and Nova Corporation a descendant of the Alberta Gas Trunk Lines. As part of the $38M deal Nortel Networks agreed to establish a wireless center of excellence in Calgary to assist the government of Alberta in its industry diversification initiative.
[22] 1999 Nortel Networks Annual Report, pp 100 note 6.

For clarity, functions not directly tied to product development have been omitted such as Finance, Marketing and Human Resources.

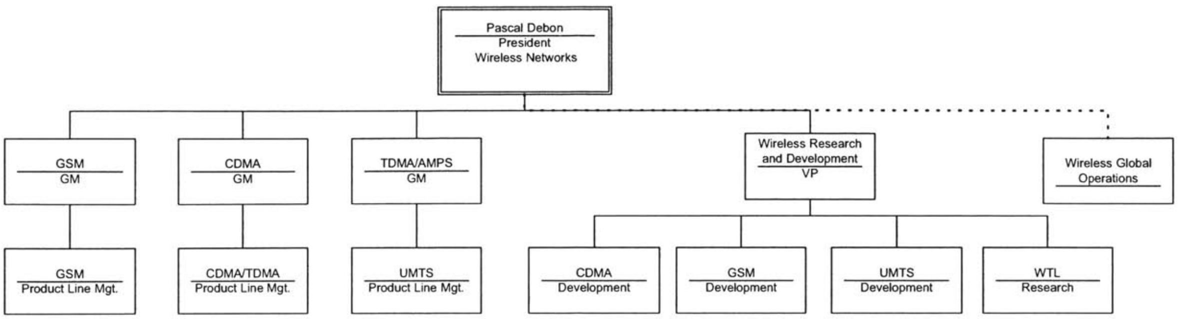

Figure 1 - Wireless Access Functional Organizational Structure 1999-2000

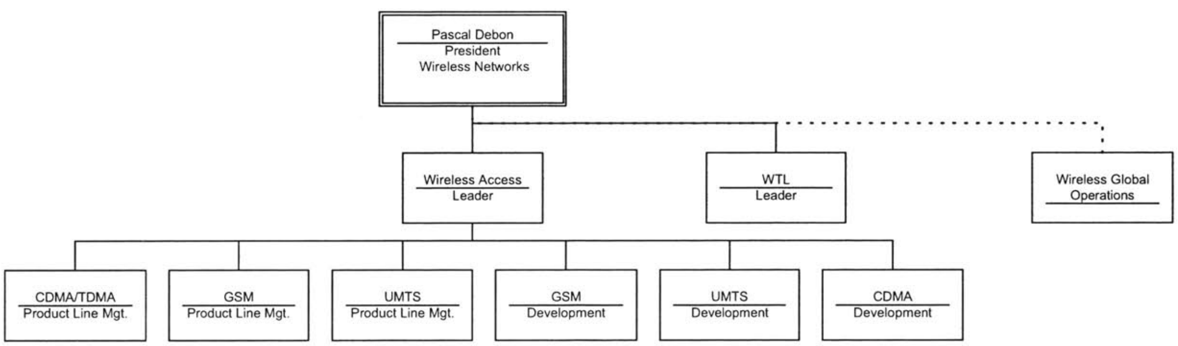

Figure 2 - Wireless Access Functional Organization 2000-2001

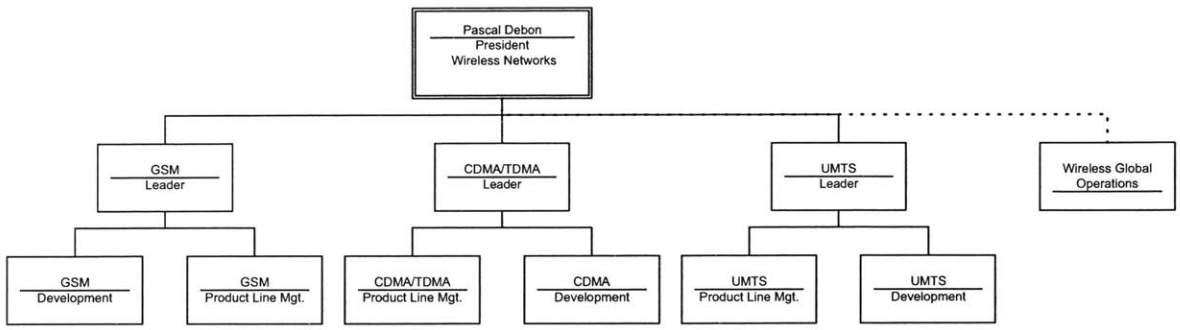

Figure 3 - Wireless Access Organizational Structure 2001-2002

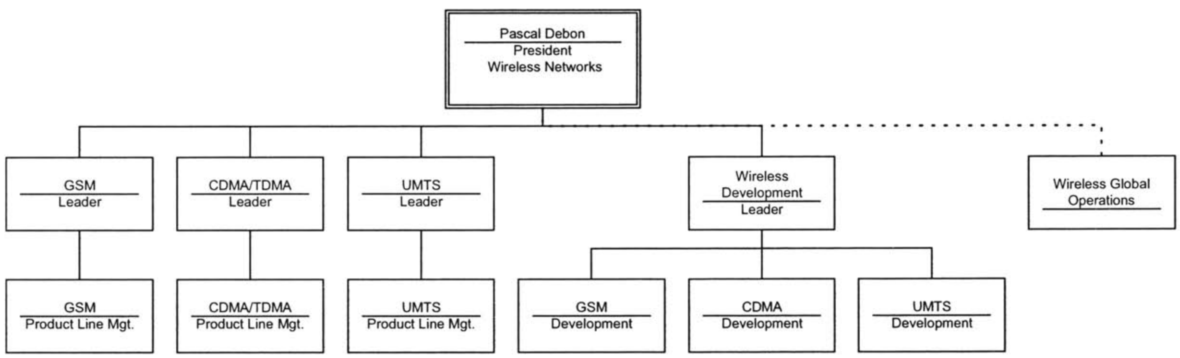

Figure 4 - Wireless Access Functional Organizational Structure 2002-2003

The functional mandates of the organizations shown in Figure 1- Figure 4 are;

Product Line Management (PLM) – are the business owners with ultimate responsibility for overall profit and loss. Each PLM organization focuses specifically on a single technology such as CDMA, GSM or UMTS. The PLM organization also has the responsibility of setting the strategic evolution of the portfolio as well as defining which new product programs to fund internally, externally or through OEM agreements.

Development – are the technical owners of a specific portfolio with ultimate responsibility for the portfolios technical compliance, bill of material cost and product field performance. Each development organization focuses specifically on a single technology such as CDMA, GSM or UMTS. A separate organization, known as the Wireless Technology Labs, conducts basic research and at the time of this study reported directly into the President of Wireless Networks. Although the two groups interact significantly, the formal reporting structures are significantly independent converging only at the Presidential level.

Global Operations (GO) – responsible for overall execution of the day to day business as well as management of the cash-to-cash cycle. Operations control the standard cost of the product as well as setting quality metrics and yield metrics and can therefore influence the profit and loss of the PLM organization directly.

1.3.3 Wireless Networks Major Operating Locations 2000-2003

Between 2000 and 2003 the Wireless Networks line of business operated out of five major locations. Table 1 provides a summary of functions and the locations from which they operated. Bolded table entries indicate prime site for each identified function and business within Wireless Networks.

Location	Function			
	President & General Managers	Product Line Management	Development	Operations
Dallas, USA	**GSM/UMTS/CDMA**	**CDMA/UMTS**		
Ottawa, Canada		CDMA	CDMA/UMTS	
Calgary, Canada		CDMA	**CDMA**	**CDMA**
Paris, France		**GSM/UMTS**	**GSM/UMTS**	
Châteaudun, France				GSM/UMTS

Table 1 - Main geographic locations of the Wireless Networks line of business 2000 to 2003

1.3.4 Time to Market Product Development Process 2000-2003

The development projects studied in this paper were all executed within the framework of the Nortel Networks Time to Market (TTM) product development process. This product development process was introduced as part of the corporate transformation strategy known as the "*Right Angle Turn*"[23]. Rather than traditional gates with fixed milestones, TTM uses event-

[23] The "Right Angle Turn" refers to a corporate transformation strategy adopted under John Roth in 1997 which was intended to empower decision making at the lowest levels of the organizations for the purpose of creating a truly agile, market driven organization. One of many outcomes was the Time to Market (TTM) development process.

driven, fact-based, business-oriented decisions which occur at specific milestones called business decision points (BDP) as a mechanism to authorize continued funding. The TTM process emphasizes risk-taking, employee decision making and a focus on rapid product development in a cross functional team environment for the sole purpose of meeting time to market objectives.

As discovered by the project teams studied in this paper, a major difference between the traditional phase gate processes and the TTM process was that the degree of overlapping development activities increased dramatically when using the TTM process. Typically, the next design iteration would start well in advance of fully completing the validation cycle of the previous design iteration.

The typical Wireless Networks TTM project team is organized as shown in Figure 5. The Integrated Product Team Leader (IPTL) is ultimately responsible for the delivery of the new product to market against agreed to quality, product cost and schedule targets. The IPTL reports into the Product Management Team (PMT), a cross-functional decision making team chaired by the General Manager or delegate. The PMT is accountable for portfolio strategy, resource allocation, and ongoing portfolio management decisions related to market timing, customer needs and business priorities.

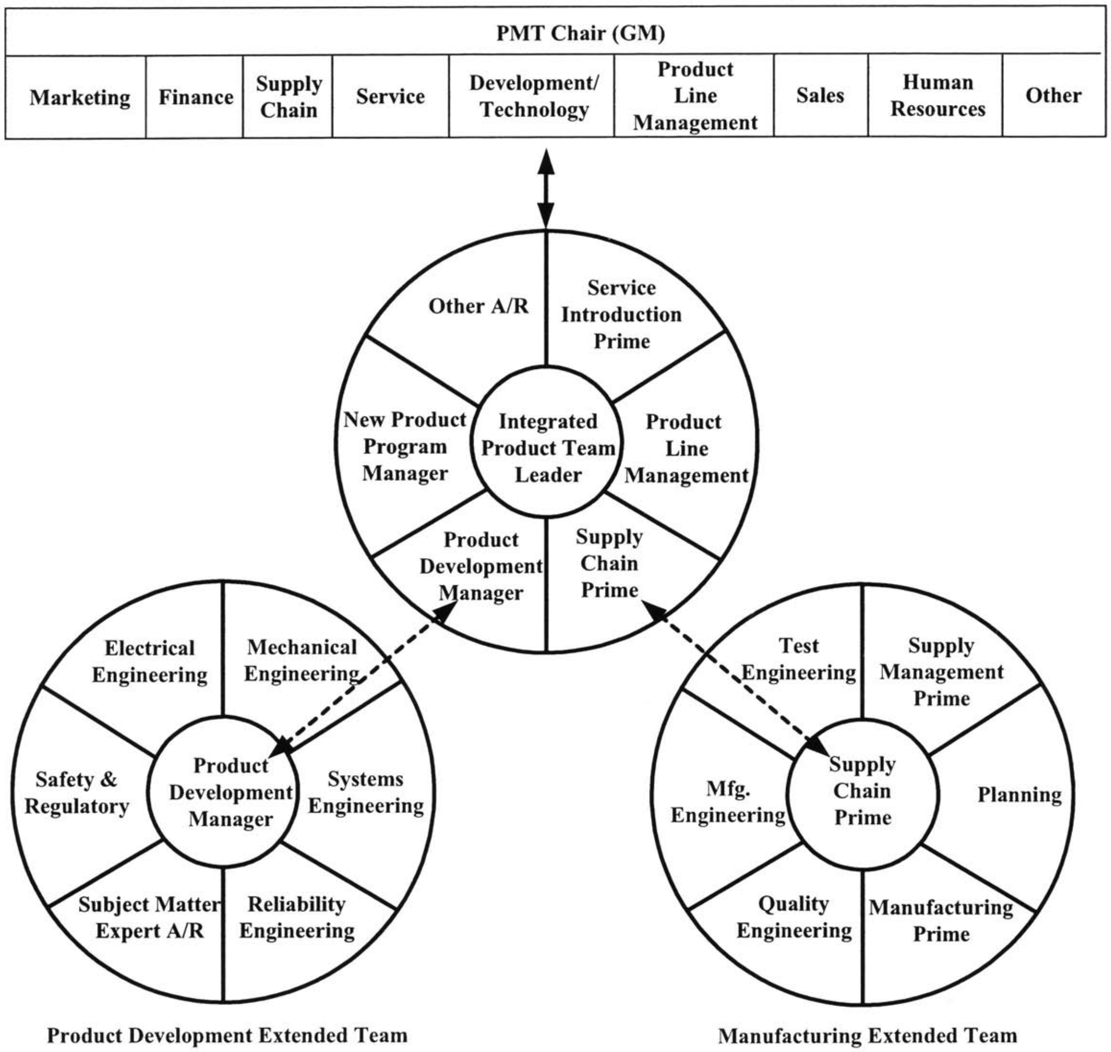

Figure 5 - Cross Functional Representation of TTM Project Development Team.

The TTM process has five distinct development phases as shown in Figure 6 below. The unclear delineation between design phases is intentional.

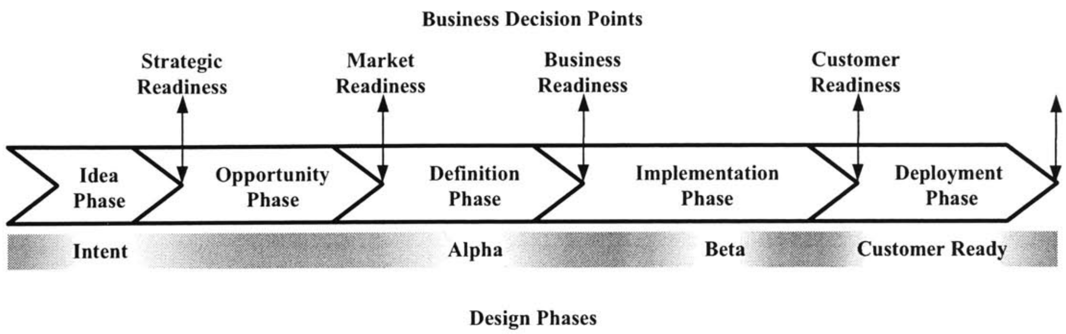

Figure 6 - Phases of TTM Product Development Process

1.4 Approach

1.4.1 Methodology

The issue of understanding the implications of a chosen commonality strategy on product development lead time was approached by analyzing four separate product development programs within the Nortel Networks Wireless business. Each of the chosen programs represents a different level of assembly within the CDMA BTS system. The key stakeholders in each of the four development teams were interviewed and data gathered. The survey[24] questions were developed within the Three Lenses[25] framework for the purpose of capturing the strategic, political and cultural views of the stakeholders with respect to their role on the development

[24] See Appendix 3 of this paper for a complete copy of the survey questions used.
[25] Ancona, Kochan, Scully, Van Maanen and Westney, 1999, "Organizational Behavior & Processes", Massachusetts Institute of Technology, South-Western College Publishing, Boston MA, ISBN 0-538-87546-1

project. The key attributes of the survey questions in relation to the development projects chosen is in Table 2.

Attribute	Increasing Degree of Program Complexity >			
	Rx Channelizer ASIC	Digital Transmit Receive Card	Radio Module	Basestation
Time to Quality	1	2	2	3
Time to Cost	3	3	1	2
Time to Market	2	1	3	1
Multi Business	X	X		X
Multi Site	X	X	X	X
Business Climate	Growth	Growth	Contraction	Contraction

Table 2 - Key Attributes of Three Lenses Questionnaire

The data gathered during the survey was analyzed in order to provide insight into the impact of organizational structure on product development lead time with respect to the implementation of a desired commonality strategy. Correlations are made between degrees of commonality and top level programmatic metrics such as quality, product cost and time to market. An evaluation of barriers preventing joint gains and acceptable compromises to be achieved amongst share holders in joint development programs is then discussed. The cultural data gathered for all projects is then analyzed using the three level entity model developed by Edgar H. Schein[26] of the Sloan School of Management. The final analysis is done to ensure that the culture of the Wireless Networks organization did not change significantly between projects or during the period 2000-2003.

[26] ibid, M2 pp 76-89. Schein, Edgar H., February 1990, "Organizational Culture", American Psychologist, American Psychologist Association

In instances where detailed programmatic data was available, a quantitative analysis was performed using a task based design structure matrices (DSM) to analyze the implication of pursuing commonality and not pursuing commonality. Effects modeled include stochastic durations, probabilistic iterations, learning effects, resource constraints, parallel tasks and overlapping tasks. The implication of commonality is then discussed.

1.4.2 Structure of Thesis

This remainder of this thesis is organized as follows: Chapter two of this thesis provides a brief industry overview with a special emphasis on the mobile wireless networking segment, current technologies and the impact of network element convergence. This is followed by an architectural discussion of the CDMA BTS using the organizational process methodology (OPM) framework and how this element fits into the overall global telecommunications network. Chapter three summarizes existing literature reviewed for this thesis and highlights differences between this thesis and previous work. A brief description of the Three Lenses framework and the DSM analysis techniques is also provided. Chapter 4 contains four sections each addressing one of the four case studies conducted. Chapter five provides a discussion of the results and chapter six contains the conclusions. Final recommendations can be found in chapter 7.

2 BACKGROUND

2.1 Telecommunications Industry

The modern telecommunications industry originated with the invention of the telephone and the subsequent first telephone call between Alexander Graham Bell and his assistant Thomas Watson on March 10, 1876. Today, the telecommunications industry represented approximately one hundred and eighty billion dollars of capital equipment (Capex) spending annually[27], is global, increasingly competitive and continues to evolve rapidly. To fully understand the rate of change in the telecommunications industry, consider that it took 100 years to establish a half-billion network terminations[28] and only six or so more years to double that number[29].

As new means of communication were developed, new networks were deployed to service these new and growing market segments. Today's global telecommunications network reflects this piecemeal evolution and as a result consists of disparate networks each addressing a unique service category such as telephony, telex, switched-packet data and so on. In all, there are seven network types as defined in Table 3. This is no longer an ideal situation considering the high cost of network management today. A *"greatly"* simplified view of today's global telecommunications network is shown in Figure 7.

[27] 2003, "Guide to Networks and Telecommunications Equipment", Lehman Brothers Global Equity Research.
[28] Network termination - the industry term to describe service points on the network.
[29] Nortel History, Nortel Networks Corporate Web Site - http://www.nortelnetworks.com/corporate/corptime/

Network Name	Main Function	Characteristics	Deployed
Public Switched Telephone Network (PSTN)	The original telephone network.	- local access, analog .3-3.4KHz; - full duplex connection; - switched bandwidth, 64 kbps Optimized for fixed voice transfer.	1876
Integrated Services Digital Network (ISDN)	Service integrated network for digital communications between user interfaces.	- local access, digital 64 kbps; - max. access rate 30 x 64 kbps Optimized for fixed voice and multimedia transfer.	1980
Public Land Mobile Network (PLMN)	Mobile to mobile telephony communications as well as communication - via PSTN /ISDN gateways - with fixed telephony subscriptions.	- air interface standards: FDMA–Frequency Division-19.2kbps* TDMA–Time Division - 9.6kbps* CDMA–Code Division -9.6kbps* *MA = Multiple Access Optimized for mobile voice transfer.	1983
Signaling System Number 7 (SS7)	Packet switched bearer network supporting communication between networks. Also support short message communication between subscribers.	- connectionless (packets treated are individually) - carries message signal units between processors in the telecommunications network.	1983
X.25/Frame Relay Packet Switched Public Data Network (PSPDN)	Cost-effective bearer network for interconnecting two LANs. Provides access from the PSTN/ISDN to the internet facilitating "home surfing".	X.25 –speed 64 kpbs Frame Relay – 2Mbps Optimized for data transfer.	1989
Asynchronous Transfer Mode (ATM) and Broadband ISDN	ATM integrates multiplexing and switching functions, is well suited for bursty traffic.	Variable bit rate 2Mbps to more than 100Mbps. Optimized for high speed multimedia.	1991
Internet Transfer Control Protocol/Internet Protocol (TCP/IP)	Packet switched using a common address structure. Unlike X.25, Frame Relay or ATM the internet is an end to end application connecting any two computers globally.	Internet protocol can technically transfer any application across any existing network. However, quality of service may suffer due to bandwidth limitations. The internet is a network of networks rather than a network in and of itself.	1992

Table 3 - Components of Global Telecommunications Network[30]

[30] Telefonaktiebolaget LM Ericsson, 2002, "Understanding Telecommunications", Lund University Press, Sweden

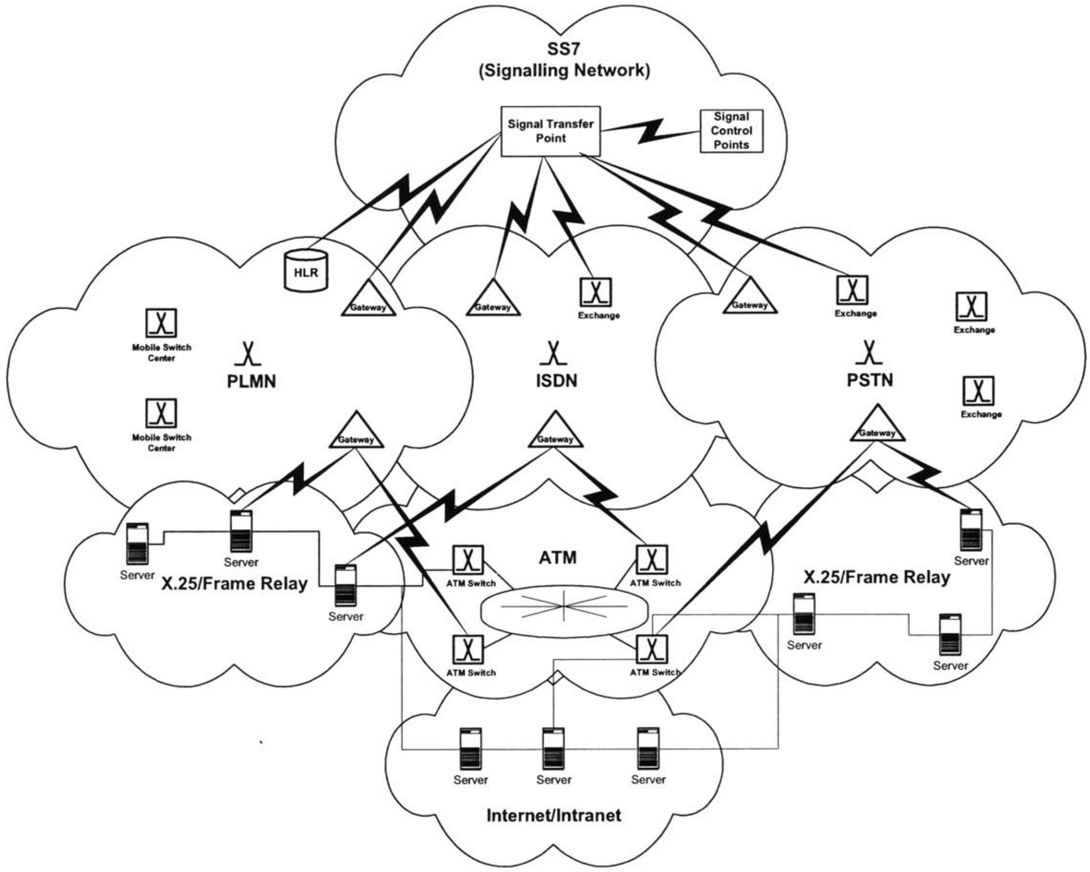

Figure 7 - Simplified View of Global Telecommunications Network

Connection to the network is provided through local telephone companies, data network or internet service providers. The service providers operate at what is known as the Network Edge. Depending on the services being offered, the physical connection to the network can be realized using mobile or fixed wireless access, optical, twisted pair copper wire and cable.

The equipment enabling the traditional network shown in Figure 7 was, until recently, dominantly supplied by major international companies such as Lucent Technologies (USA), Nortel Networks (Canada), Alcatel (France), L.M. Ericsson (Sweden) and Siemens (Germany) each benefiting from the heavily regulated telecommunications monopolies within their respective countries.

2.2 Convergence and the Transformation of the Network

With the advent of the internet, world wide de-regulation of the telecommunications industry and the introduction of mobile wireless access, the industry has undergone dramatic change. With respect to deregulation and then internet, Nicholas Negroponte of the MIT media lab wrote *"Worse, the entire economic model of pricing in telecommunications is about to fall apart. Today's tariffs are determined per minute, per mile, or per bit, all three of which are rapidly becoming bogus measures"*[31]. When asked whether the evolution of the internet was significant, Andrew Grove of Intel Corporation wrote, *"Anything that can affect industries whose total revenue base is many hundreds of billions of dollars is a big deal."*[32] . In this increasingly competitive global market place, network convergence and transformation are required in order for incumbent service providers to remain competitive.

The vision of the new, transformed network is one in which disparate network elements are converged onto single architectural platforms serving the Client, Wireless Access, Network Services, Multi-services Packet, VoIP, Multi-services Optical and Element Management aspects of the network architecture. The Nortel Networks view of the transformed network topology can be seen in Figure 8. Also, the convergence of disparate network elements into single

[31] Negroponte, Nicholas, 1995, "being digital", Alfred A. Knopf Inc., New York, ISBN 0-679-43919.
[32] Grove, Andres S., 1996,"Only the Paranoid Survive", Bantam Doubleday Dell Publishing Group, Inc., New York, ISBN 0-385-48258-2.

architectural platforms is rapidly reducing the need for highly specialized telecommunications equipment.

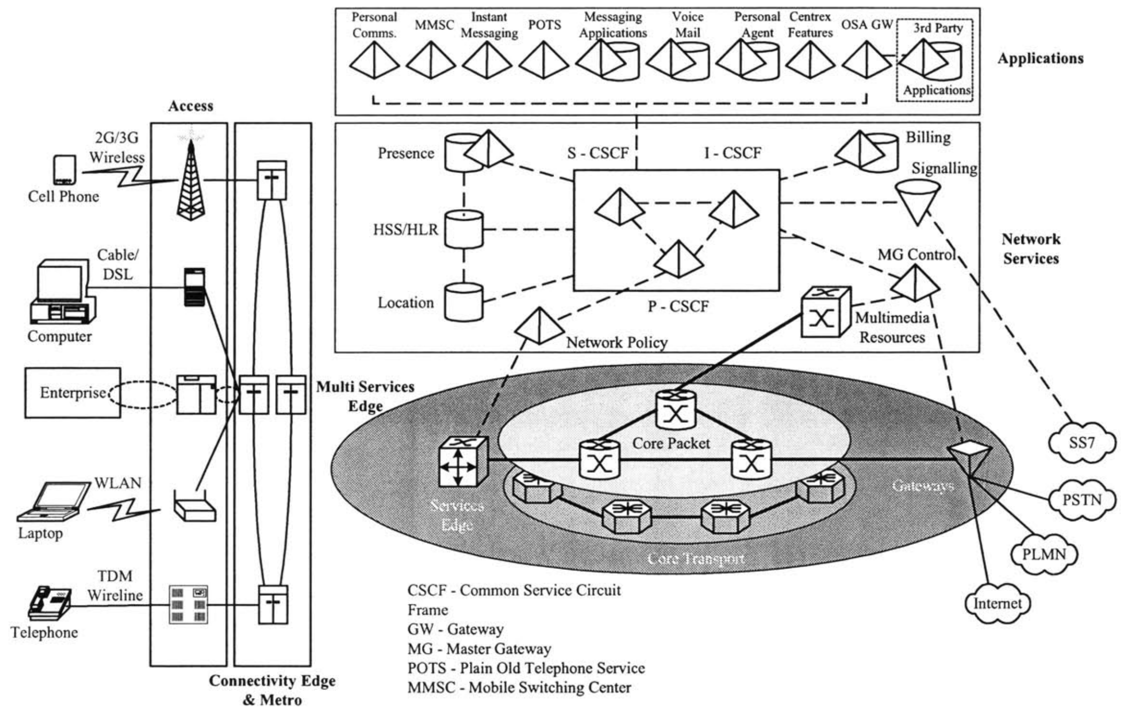

Figure 8 - Nortel Networks Transformed Network Topology[33]

The edge of the transformed network is typified by routers, soft switches and computer servers consequently changing the competitive environment within the telecommunications equipment industry as shown in Figure 9.

[33] Source Nortel Networks

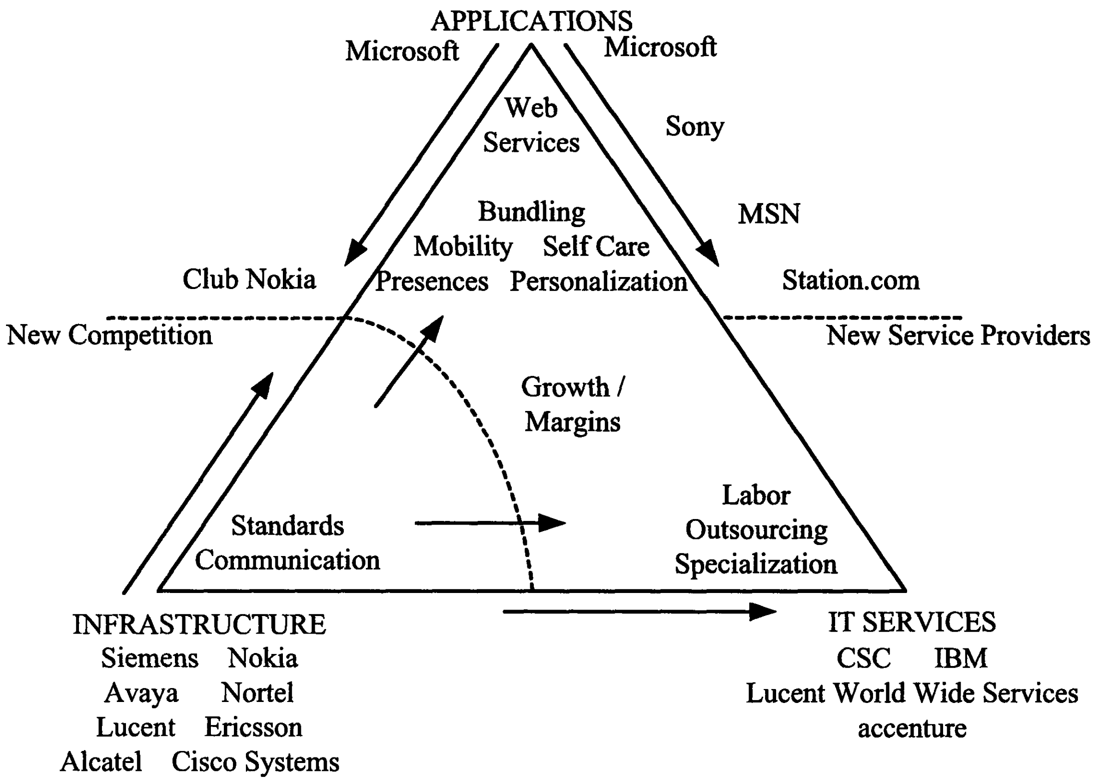

Figure 9 - Changing Competitive Environment[34]

Revenue growth opportunities are viewed as having migrated from the traditional core portion of the network to providing value at the edge of the network through ubiquitous voice, data and multimedia services to the end user as shown in Figure 10.

[34] Source Nortel Networks

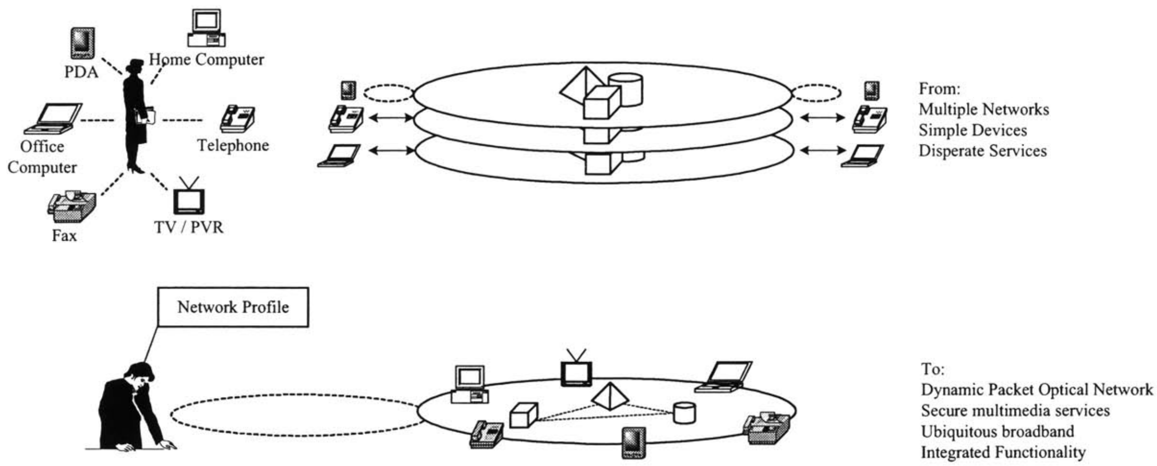

Figure 10 - Transformed Network User Value[35]

As well as deregulation and the internet, the third area which is rapidly evolving is that of mobile wireless access. As one of the most cost effective ways to deploy last mile connectivity, mobile wireless access networks are rapidly being deployed throughout the developing world.

With the introduction of third generation (3G) standards, there are two competing air interfaces to choose from, namely CDMA 2000 (CDMA North America) and W-CDMA (UMTS Europe). Technically, both are similar enough that it is possible to have a common base transceiver station (BTS) architecture servicing both standards. Within the industry, Ericsson has chosen to develop a fully common BTS servicing both UMTS and CDMA markets. Lucent Technologies and Nortel Networks, two major competitors within this segment, have chosen to pursue lesser degrees of commonality between their BTS platforms whereas Nokia Corporation

[35] Source Nortel Networks

has chosen to pursue a completely open non proprietary architecture through support of the Open Base Station Architecture Initiative.

2.3 Mobile Wireless Access

For the purpose of this paper, we will only discuss the CDMA and UMTS wireless access nodes commonly referred to as BTS. The topology of the CDMA mobile wireless access network is given in Figure 11 as reference. As the technologies are quite similar the deployment of UMTS BTS is comparable with CDMA BTS. As the access node, the BTS is the most heavily deployed network element having one BTS per wireless cell.

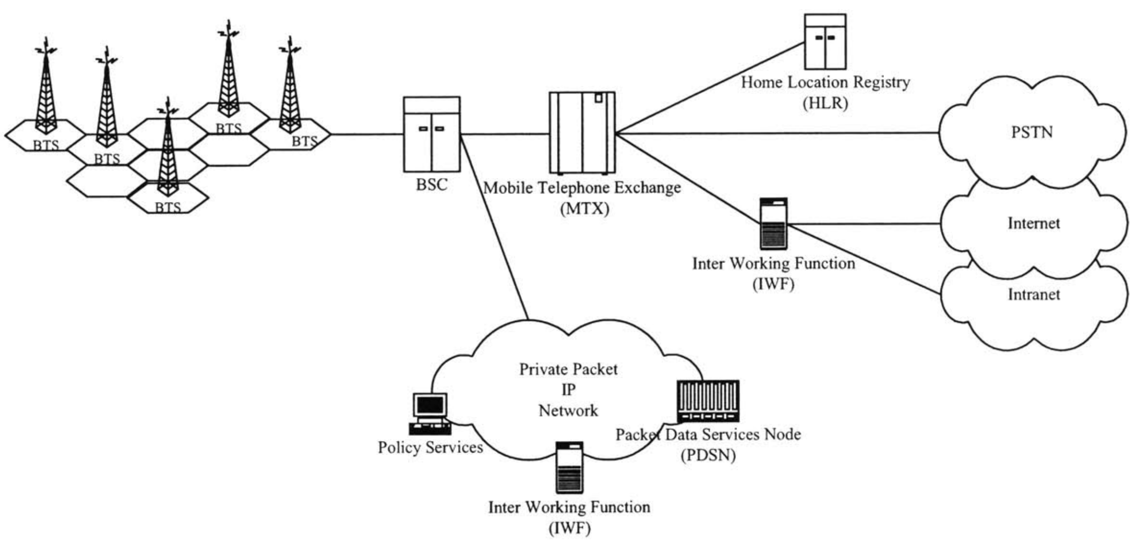

Figure 11 - CDMA Wireless Access Topology

3 LITERATURE REVIEW

3.1 Literature Review

The benefits of implementing a commonality strategy have been well documented in the literature. Meyer and Lehnerd, (1997)[36], site several successful examples from Hewlett-Packard, EMC and Black & Decker in which commonality across platforms was embraced and implemented successfully. In fast clock speed industries, such as consumer electronics, Sanderson and Uzemeri, (1994)[37], use the case of the Sony Walkman as an example of where a good use of process and platform commonality were essential elements of a short time to market development cycle. Using queue theory, Reinertsen, (1997)[38], shows how prudent use of common parts can reduce uncertainty in the product development cycle ultimately leading to shorter overall development times.

The organizational complexities associated with the implementation of commonality strategies have also been studied. Cratty and Sahutske, (2003)[39], analyze various organizational structures with respect to their impact on the implementation of a commonality strategy. A framework of metrics by which to measure the long term benefits of a commonality/platform strategy within a design firm were derived by Meyer, Tertzakian and Utterback, (1997)[40]. Further insights into the impact of organizational structure on the executions of tasks can be

[36] Meyer, Marc H. and Alvin P. Lehnerd, 1997, "The Power of Product Platforms", New York, The Free Press, ISBN 0-684-82580-5

[37] Sanderson, Susan and Mustafa Uzumeri, 1995, "Managing Product Famalies: The case of the Sony Walkman", Research Policy 24 (1995) 761-782., Elsevier Science B.V.

[38] Reinertsen, Donald G., 1997, "Managing the Design Factory", The Free Press, New York, ISBN 0-684-83991-1

[39] Cratty, Lisa and Matthew Sahutske, 2003, "Modeling & Developing a Commonality Strategy in the Automotive Industry", Thesis, System Design and Management, MIT.

[40] Meyer, Marc, Tertzakian, Peter and James Utterback, 1997,"Metrics for Managing Research and Development in the Context of the Product Family", Management Science, Vol 43, Issue 1 (Jan., 1997), 88-111

analyzed using a three level entity model developed by Edgar H. Schein[41] of the Sloan School of Management.

The impact of communication between design groups working on an integrated development project has been analyzed by Sosa, Eppinger and Roles, (2000)[42]. In their study, they sought to understand the effects of product architecture on technical communication in product development organizations. This work extensively uses the design structure matrix[43] (DSM) to analyze the impact of organizational structure and architecture on product development lead time.

The current literature does not appear to address product development programs in which software development constitutes a full 70% of the effort and typically takes longer than the development of the hardware platform itself. Most telecommunication equipment falls into this category. In a fast clock speed industry such as telecommunications, the implications of Time to Market, Time to Cost and Time to Quality need to be explicitly considered as they are not always equally important.

[41] Schein, Edgar H., February 1990, "Organizational Culture", American Psychologist, American Psychologist Association

[42] Sosa, Manuel, Eppinger, Steven and Craig Rowles, 2000, "Understanding the Effects of Product Architecture on Technical Communication in Product Development Organizations", Sloan School of Management Working Paper Number 4130.

[43] Cho, Soo-Heng and Steven Eppinger, "Product Development Process Modelling", Proceedings of ASME 2001 Design Engineering Technical Conference, DETc2001/DTM-21691, Pittsburgh PA, September 9-12, 2001

4 CASE STUDIES

The following case studies pertain to development activities between 2000 and 2003 within the Nortel Networks CDMA business. The product hierarchy of a typical CDMA BTS is shown in using standard Object Process Methodology[44] (OPM) nomenclature. There are a total of five levels of hierarchical design decomposition for a CDMA BTS.

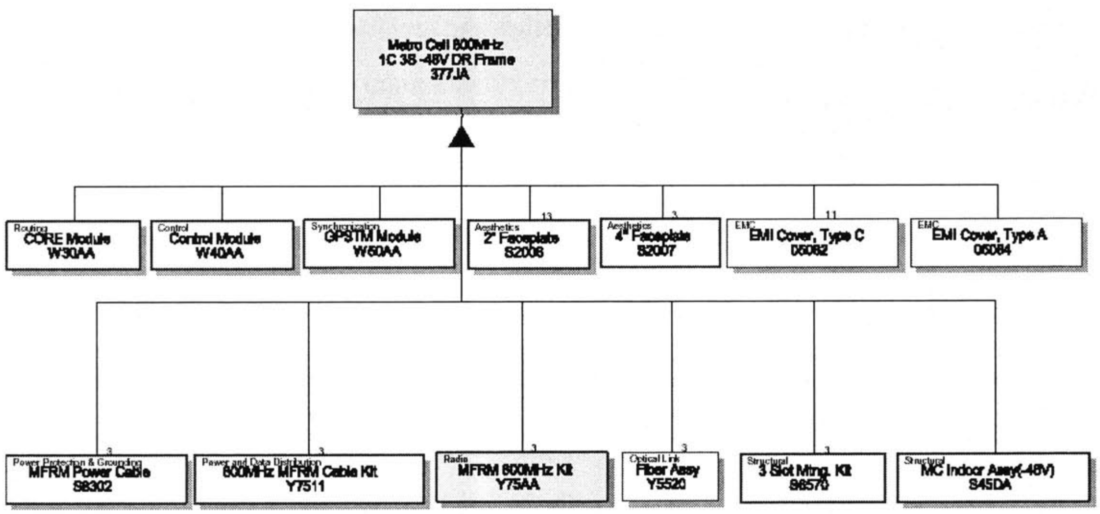

Figure 12 - CDMA BTS Level 0 and 1

[44] Dori, Dov, 2002, "Object-Process Methodology", Springer-Verlag, Berlin, ISBN 3-540-65471-2

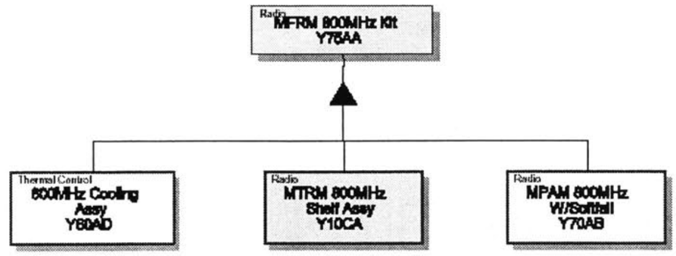

Figure 13 - CDMA BTS Level 1 and 2

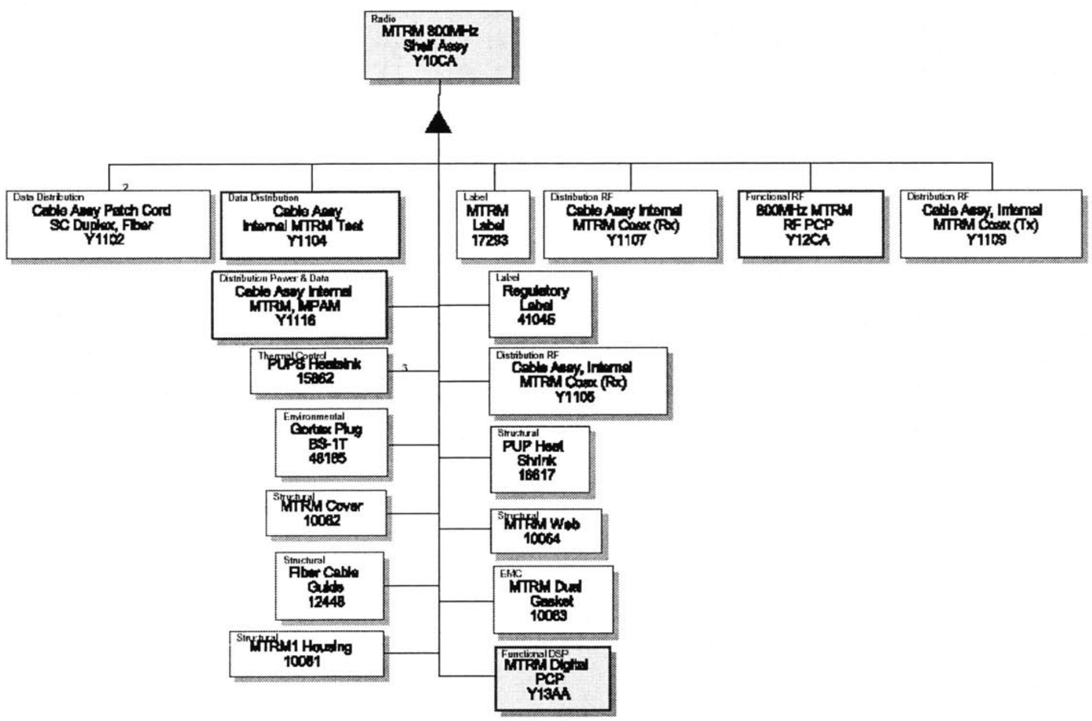

Figure 14 - CDMA BTS Level 2 and 3

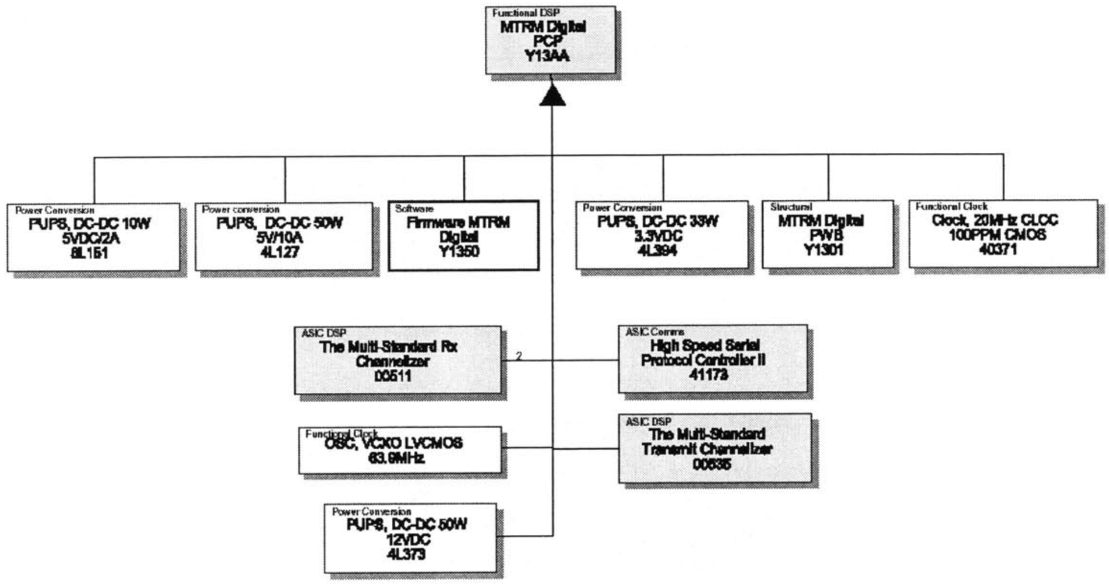

Figure 15 - CDMA BTS Level 3 and 4

4.1 Multi-Standard Receive Channelizer ASIC

The multi-standard Receive Channelizer ASIC (Rx ASIC) supports both UMTS (Universal Mobile Telephone System) and CDMA 3G standards. The Rx ASIC is capable of supporting up to six 2G channels or two 3G channels which are nominally split equally for main and diversity reception. The Rx channelizer performs digital channel selection consisting of: ADC interfacing, quadrature demodulation (optional), channel tuning, channel selection (filtering), AGC (automatic gain control), and interfacing to the high speed serialization device (HSSPC-II). The Rx ASIC is implemented using the Texas Instrument's GS30 1.8-V CMOS standard cell technology[45]. The Rx ASIC is a part on the digital transmit receive (DTRx) printed

[45] Morris, Brad, 2000, "Multi-Standard Channelizer General Specification", Issue 3.1, Nortel Networks

circuit assembly located at the fifth level of product hierarchy shown in Figure 15. A functional block representation of the RF/IF and digital signal paths are given in Figure 16 for reference.

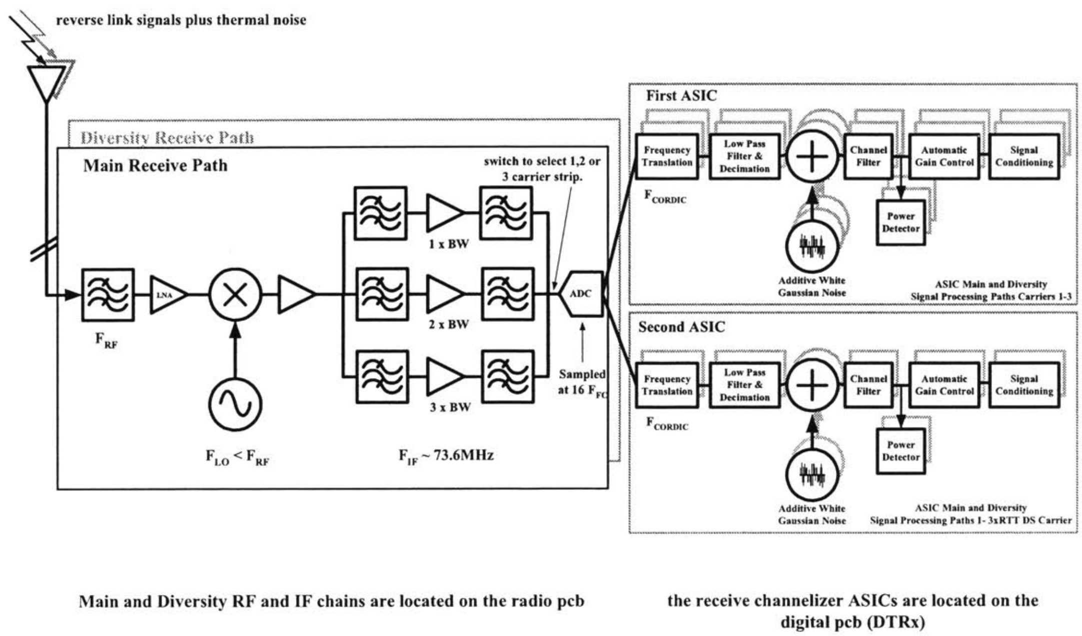

Figure 16 - CDMA BTS RF/IF Signal Flow Functional Block Diagram

Physically the part is realized in an industry standard plastic one hundred and ninety six ball grid array package shown in Figure 17.

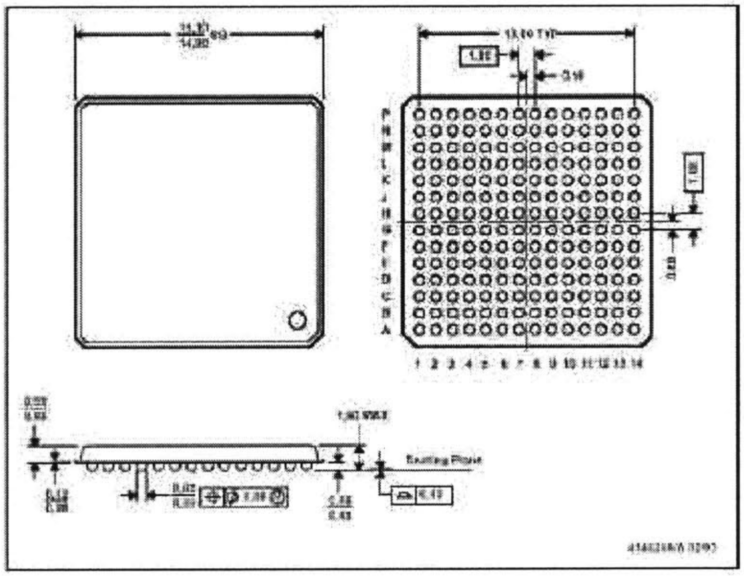

Figure 17 - Rx Channelizer Package

In 1997, a corporate mandate was given to the Wireless Technology Lab (WTL), the corporate research group for wireless technology within Nortel Networks, to develop a wideband experimental system. The purpose of this wideband experimental system was to gauge industry interest in wireless 3G technologies such as UMTS and CDMA 1xRTT as well as to demonstrate Nortel Networks competency and commitment to the wireless market. By 1998, the wideband experimental system was being demonstrated at various trade shows globally. The implementation of the required DSP functionality within the wideband experimental system had been accomplished using field programmable gate arrays (FPGA).

Interest in wireless 3G technology, within the industry, proved to be strong and the focus within WTL shifted to their secondary mandate which was the commercialization of new technologies. The following is three lenses analysis of the multi standard Rx and TX Channelizer ASICs development project focusing on the implications of the commonality strategy chosen on product development lead time.

4.1.1 The Three Lenses

Strategic Lens

The main thrust of the commercialization effort was to consolidate the DSP functionality implemented using multiple FPGAs on the wideband experimental system onto two ASICs, one for receive (Rx) and the other for transmit (Tx). Both the Rx and Tx ASICs were to be capable of servicing the future 3G needs of both the CDMA and UMTS businesses. The leader of the WTL organization felt that a common ASIC development program between WTL, CDMA and UMTS would offer three advantages to Nortel Networks. The cost benefit in using an ASIC vs. FPGA was approximately $8 vs. $400 respectively. The schedule for a collaborative ASIC development could benefit greatly by leveraging the experience gained by the WTL team in working on the experimental wideband system. As well, the quality of the resultant ASICs would be high as each functional block required by the ASIC had already been proven on the wideband experimental system. The functional blocks with the exception of the peak power ratio (PPR) block were therefore available in an advanced prototype state before the CDMA/UMTS architects had even a chance to read the 3GPP specifications.

The WTL team promoted the idea of a common channelizer ASIC through a traveling road show to the Paris, Calgary and Ottawa R&D centers. The presentation was made to each respective general manager (GM), product line management organization (PLM) and product development organization. The basic premise for the promotion was one of reduced cost and reduced time to market. As captured in the quote below the WTL team felt it was a Win-Win-Win proposition to all stakeholders.

"As WTL, we did not have an inherent interest in either business and were therefore able to define a neutral set of requirements for both businesses. We provided a non biased view of the problem and the solution. I personally acted as the architect. Our interest was to achieve commonality for the overall benefit of Nortel Networks." - WTL Development Manager.

The agreement to proceed with a joint development program on a common Channelizer ASIC was reached at the director level within the CDMA and UMTS product development organizations. As there were no objections to the proposal from either GM or either PLM organization, the decision to go ahead was strictly borne by the technology teams within Nortel Networks. The CDMA development team adopted the proposal quickly as they already had a single carrier ASIC solution which they could fall back on if things didn't work out. The UMTS team on the other hand was leaning toward an FPGA based implementation strategy due to a bad experience with ASICs development on the GSM product. With time, the WTL team who had trialed multiple schemas for channelization and viewed the use of FPGAs as a non realizable option were able to persuade the UMTS team to abandon the FPGA approach and focus their effort on a joint development program for an ASIC.

One of the primary drivers leading to the receptiveness of the CDMA and UMTS development organizations in accepting the proposal was the general shortage of qualified resources within both organizations in 1999-2000. The proposal provided both organizations with a means to get the job done with minimal cost and time. Both design teams provided resources to the detailed design effort and both design teams ratified all of the basic decisions for the project. Participating in this way was viewed as less labor intensive for both the CDMA and UMTS product development teams.

In essence, the WTL group became responsible for generating the project plan for the ASIC development, getting approval to proceed from both of the stakeholder teams as well as securing funding for the project. The WTL group acted as the technology vendor to both the CDMA and UMTS lines of business. In this role, the WTL group helped consolidate the requirements in the form of a system design specification (SDS) from both stakeholder groups and formulate a general specification (GS) which was ratified amongst the three stakeholders WTL, CDMA and UMTS.

Upon ratification of the GS, a prime from the WTL organization was put in place for the purpose of facilitating the review of new feature requests from either business. Factors such as cost and schedule were considered and both teams had equal veto power on any new feature being proposed. The PLM organizations from each line of business were now actively involved in the process as the non recurring engineering (NRE) costs were being shared between the two lines of business.

The development team consisted of approximately ten dedicated resources assigned from the WTL organization with one or two resources from each of UMTS and CDMA providing inputs. The development effort was managed under one functional manager within the WTL organization who was responsible for both the Tx and Rx channelizer ASICs. The partitioning of the design was defined by the DTRx card interfaces. Since the WTL team were involved in designing both the ASICs and the DTRx card, defining the interfaces between them was straight forward. The interdependence between tasks on this program was organized in a reciprocal manner as shown in Figure 18.

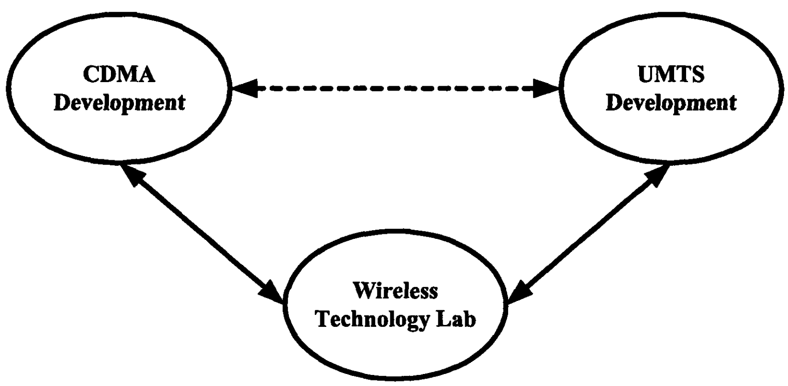

Figure 18 - Rx Channelizer Program Structure (Reciprocal Interdependence)[46]

Feedback from those interviewed indicates that the structure of the project reduced churn primarily due to the extra effort invested in ratifying the GS between the two groups.

[46] James Thompson, 1967, introduced a topology of task interdependence - reciprocal, sequential and pooled.

"Once the specifications were ratified between the three organizations there was never any force to disengage from the commonality mandate set." – WTL Development Manager.

"After the GS was ratified it went very well." – WTL Feature Review Prime.

"The whole project was very structured around the commonality goal. There was no doubt that the channelizers would remain common. The General specification was consolidated and written by WTL. WTL also drove all of the design reviews. My counterpart and I would communicate via email outside the formal reviews. Because of the time difference between Calgary and Paris, this worked surprisingly well. I would ask a question and the next morning I would have an answer and vice versa." – CDMA Design Prime.

"The commonality was managed by WTL. Both sides worked on their own with WTL pulling ideas from both sides together. In essence, I viewed WTL as a node that I was working with. There was a definite need for structure to achieve commonality as the CDMA and UMTS requirements were different." – UMTS Design Prime.

The impact to product development lead time, due to the commonality strategy chosen, manifests itself in several key areas. As mentioned above, the serial activity of requirements gathering and synthesis, proved to be the most time consuming part of the project taking a full seven months to complete. This was estimated as a 200% increase in effort and time in comparison to a no commonality. Although the involvement of multiple groups early on slowed the project during the requirements definition phase, this proved to be beneficial during the later stages of the project as unnecessary churn was more thoroughly challenged. This was referred to as the "churn dampening" effect by the team. Also as the functionality requested by each group differs somewhat, some ASIC gates were "common use" and others were not. Estimates by the team indicate that 50-75% of the blocks were different contributing to approximately 30% more effort on the detailed block design portion of the development cycle. This effect would be similar to carrying extra functionality on a part in order to maintain commonality across more platforms. The physical manufacturing process, which accounts for 25% of the total work, however, remained unaffected by the design differences between the UMTS and CDMA applications. The ASIC test and verification work was carried out by the CDMA and UMTS lines of business independently. The total duration of this activity was equal to that of a non common part. However, the effort was double as the two teams worked in parallel.

During this program, time to market (TTM) dominated the metrics by which the program was being measured. There was only one schedule slip which was accepted by both the CDMA and UMTS PLM organizations as other portions of the larger 3G wireless program into which this ASIC development fit were even later. Even though the program was driven aggressively, the quality achieved was considered to be very high. The commonality strategy once set was maintained and successfully implemented throughout the program. Four years after the completion of the development effort the common Rx channelizer ASIC is still viewed as a very high quality and cost effective part.

"The quality of the ASIC was never questioned, by definition it had to be right. This was also the cheapest option in achieving the required functionality." – WTL Design Manager

Strategically, the team was formed for the sole purpose of developing a common channelizer ASIC. The CDMA and UMTS product development teams were involved in this activity for the sole purpose of ensuring that the end product would meet the requirements of each respective business.

Geographically, the teams were spread across three locations namely, Ottawa, Calgary and Paris. Surprisingly, based on interview feedback, these geographical differences and multiple time zones did not drive up the number of meetings held. In some cases, it was actually beneficial to have multiple time zones as work progressed through the night. In other cases, it was not and travel was required. Fortunately, the preference of the Paris team was to start work later in the day relative to their counterparts in Calgary who preferred to start early. However, there are indications that the amount of time spent traveling increased significantly for the team members in the Calgary location. Language was a bit of an issue, especially with teleconferences. However, most people at the Ottawa site have a working knowledge of the French language. Language differences were therefore not a significant impact to the project.

Strategically, the initiative was well aligned with the TTM, TTC and TTQ metrics of both lines of business. The initiative was also well aligned with the secondary mandate of the WTL group to commercialize their research technology into existing or new products. The activities of each stakeholder were closely linked (reciprocal interdependence) reflecting the complex and iterative nature of the task being executed. The grouping of activities was also congruent with the desired output of a common channelizer ASIC. Having both lines of business participate was a key factor in ensuring that the part met all requirements.

The Political Lens

In all, there were five primary stakeholders involved in the development of the common channelizer ASIC. At the highest level, these can be grouped into the WTL corporate function, the CDMA Development and PLM organizations and the UMTS development and PLM organizations. The functional mandates of each of these groups as well as their roles and responsibilities are given in section 1.3.2 of this paper. At the time of this project, the CDMA business was under tremendous pressure to develop 3G capability within their portfolio and the UMTS business was under tremendous pressure to introduce a new 3G platform. Funding for development was not an issue as both businesses viewed 3G capability as vital to their future growth and survival. However, both the CDMA and UMTS businesses were resource constrained. Hiring and training new resources was viewed as an impractical method of achieving the business objective. The WTL organization had the required resources and skills needed to do the work due in large part to the experience gained in developing the wideband experimental system.

The WTL organization also wanted to establish themselves as the DSP center of excellence within Nortel Networks continuing to justify their existence as a separate entity which was not aligned with either line of business. As part of the WTL organizations mandate, a certain percentage of their annual budget was to be allocated to commercializing new technology.

There were indications that previous attempts to commercialize new technologies out of the WTL organization had a mixed track record of success.

In the WTL proposal for a common development effort on the channelizer ASIC, the WTL organization would pay for and supply the labor and the CDMA and UMTS businesses would pay for the NRE which was the bulk of the expense of the program. In this proposal, it appears that the zero-sum game[47], the natural point in which power constrains organizational choices to the current entrenched interests, was altered. Through the generation and sales of the proposal, the WTL organization was able to show that the overall zero-sum pie could be expanded in everyone's interest. When viewing *"power as the ability to get things done, one can better visualize the character of power as a force that is both constraining and producing"*[48].

Ultimately, the WTL organization was able to gain the trust of the CDMA and UMTS lines of business by demonstrating capability through the wideband experimental system and through the structure of the proposed development team in which a high level of transparency and fairness to each business could be ensured. As commonality did not impact or restrict either business from achieving or receiving their requested functionality, the issue of a joint development program was viewed as a business decision. It was borne out of the technology organizations as it was basically a transfer of design authority, at the piece part level of assembly, from the CDMA and UMTS development organizations to the WTL organization.

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[47] Ancona, Kochan, Scully, Van Maanen and Westney, 1999, "Organizational Behavior & Processes", Massachusetts Institute of Technology, South-Western College Publishing, Boston MA, ISBN 0-538-87546-1
[48] ibid

After project kickoff, the members of the development team viewed their work as strictly technical and were effectively buffered from outside influences by the WTL design manager.

"At the time, I had no visibility of the direct business impact of what I had been asked to do. I had no influence on the commonality decision; I was decoupled and isolated from it." – CDMA Design Prime.

"We received the requirement from PLM to drive for a common Rx Channelizer ASIC. We subsequently tried to influence the decision based on business needs at the time." – UMTS Design Prime.

Discussions around timelines and funding were limited to the WTL development manager and the CDMA and UMTS PLM representatives who pushed the schedule very hard. The fact that the pursuit of commonality did not impact or restrict either business from achieving or receiving their requested functionality was viewed as beneficial and it allowed the team to focus primarily on the technical issues. However, the CDMA line of business still felt it necessary to place the following constraints on the program prior to agreeing to proceed;

"The development schedule had to meet the business needs, the new ASIC had to be at least as good as the existing ASIC and the project had to be able to cope with last minute CDMA churn." – ASIC Architect

The UMTS business had the tightest schedule and no backup plan. This changed when the UMTS market fell out toward the end of 2000 but TTM was the major driver during the program kick-off and requirements gathering phase. Given the mandate of the WTL group and their role in this project, it is clear that they had the most at stake if a high quality level was not achieved. Although time to market was a significant concern, schedule requirements between UMTS and CDMA lines of business were disjointed. One team wanted more functions added which of course took more time. As both teams needed the ASIC to work, a solution had to be reached within the commonality strategy chosen.

In order to ensure equity, each stakeholder group had veto power, spent equal amounts of money and had equal representation on the ratification team[49]. Tradeoffs were performed using a majority voting system as there were three groups involved. If one group said something was wrong, the others had to check it out. If two groups said there was something wrong, then the error had to be fixed. The three key technical members of the team got along well and respected each others skills and knowledge. Over time, the role of each key technical contributor evolved. For instance, the role of the WTL development prime evolved into the person who looked at how the channelizer would ultimately be used. They effectively transitioned from a low level block designer to functional architect. According to the team, the collaborative decision making model was viewed as necessary although it was at times more cumbersome to follow.

There were also technical constraints (targets) for cost, power consumption and ASIC pin designations. Any new features that fit into these constraints were typically rolled in. The major

[49] At the time neither the CDMA nor UMTS businesses were dominant over each other. This was based on the fact that the future growth potential of UMTS was given credit to the point of equality with the existing size of the CDMA business.

differences occurred at the detailed level where the impacts where minimal. Each of the sponsors CDMA and UMTS would document what they wanted and the WTL feature review prime would respond with a cost and schedule impact when applicable. The development representatives from each of the sponsor groups would approve or disapprove of new requests and in the case that an escalation was required the PLM organization from each sponsoring organization would make the ultimate call. This apparently only happened once and even then the commonality strategy was never challenged or changed. As the WTL group was also designing the next higher level assembly, the DTRx card and the high speed serial link (HSSL), system interfaces had been defined by them already making the ASIC more straightforward in its implementation.

"It was excellent for both CDMA and WTL. The result was excellent. A good example of what can be done together." – UMTS Design Prime

The Cultural Lens

The significant change in Nortel Networks corporate culture came in 1997 with the Right Hand Turn initiative headed by John Roth. Terms such as web speed and time to market became the new hallmarks of corporate communication as the organization underwent its transformation from a traditional telecommunications equipment provider into an agile internet defining corporation. The traditional culture of employee entitlement was rapidly replaced with a culture of employee differentiation. It was well known that differentiating one self from the rest of one's peers led to larger salary increases and bonuses. Stock options were also introduced as incentives to the engineering staff for the first time and became extremely popular as the Nortel Networks share price continued to defy gravity and rise in value every week.

At each site within Nortel Networks, this transformation took on its own subculture based largely on the sites origins. The subcultures of the three organizations involved in this development project are given below.

The Wireless Technology Labs originated out of the original Bell Northern Research group in Ottawa. The group has a large proportion of engineers and scientists with graduate degrees. Many of whom are known within the industry as experts in their field. The organization focuses on new wireless technology and the research associated with it. They do not have to deal with the daily *"noise"* associated with running a business or servicing an urgent customer need. The employees within WTL typically have a Nortel Networks mindset and view the organization as one entity trying to optimize the whole rather than each of the parts independently. The engineers interviewed from the WTL organization view themselves as being less conservative than their UMTS counterparts in France and more conservative than their CDMA counterparts in Calgary.

The CDMA organization originated out of the purchase of Novatel Wireless. It is viewed as entrepreneurial and is typically seen as taking unnecessarily large risks both technically and programmatically.

"Everything was going to be successful and we had complete confidence in everything we did. Wireless Networks was still small enough within Nortel Networks that we were able to take much larger risks than we can today." – CDMA Design Prime.

Decision making is consensus based and employees are encouraged to communicate their opinion during the consensus process. Once consensus has been reached, the whole team rapidly falls in line and executes against the agreed to plan. The subculture is one of very little argument or passive resistance once consensus has been reached. The CDMA development engineers pride themselves in their can-do attitude and view it as a differentiator within Nortel Networks. They typically work in large teams with specific specializations for each team member.

The UMTS organization originated out of the acquisition of Matra communications and is viewed as being very conservative. The organization typically wants to study multiple options before proceeding. For example, the UMTS team was very averse to the use of ASICs. This was due primarily to a bad experience a few years earlier on GSM in which the ASICs were not only late but of poor quality. As with the CDMA organization, the UMTS development organization prefers to do things themselves. They view themselves as a rational entity that continues to operate within its own operational norms even when faced with contradictory direction or mandates from outside their organization. The UMTS organization typically works in teams as well but rely on their engineers to have a more global view of the overall system rather than specialization.

"I don't understand the Nortel Networks culture; I don't see a clear line to follow. The lines change constantly. We do what we think is right. We have the same culture today as we have had for the last 4 years." – Anonymous.

Given these differences in subculture, the general consensus amongst those interviewed was that there were definitively functional silos at the time. The "not invented here syndrome" was prevalent within all the wireless development organizations at the time. Everyone had their own opinion on how things should be done. If there were two product groups trying to do the same thing, you needed a neutral broker to facilitate the requirements definition.

Adding to this was the unique culture of the UMTS team which needed to be accommodated for. Having evolved out of the Matra GSM organization, they were a new entity who needed to establish their *"place at the table"* within the technology community.

As each stakeholder group wanted to be well represented, they provided the top technical resources out of their respective development organizations.

"The UMTS team knew they had a well defined problem. The two representatives from UMTS were excellent to work with. They were very interested in learning everything they could about CDMA. The representatives that were from both CDMA and UMTS were very cleaver and worked together very well." – WTL Feature Review Prime.

The concept of shared development and ultimately the transfer design authority to a third party were contrary to the culture within either the CDMA or UMTS development organizations at the time. With the formation of the team, a new subculture emerged. This subculture was not aligned with any particular site or line of business but was more influenced by the individual team members many of whom had never previously worked together.

"It was clear from the start to all of us that we had to work together." – WTL Feature Review Prime.

Another subculture within the development community is that of the *"tribal elder"*, a certain engineer, who has earned the respect of his/her, peers and consequently holds unusual influence over technical decisions. These individuals are typically considered the *"cleverest or most influential engineers by their peers"* and can typically get things done outside of normal channels or processes by simply asking nicely. The incident is described below.

"One of the designers from the old TDMA radio group asked us to implement an I/Q imbalance functional block out of the blue without justification. And we did! This was unusual as the block was never used. There seemed to be some people within the organization for whom the rules didn't strictly apply." –CDMA Design Prime.

To a large extent, the culture which emerged within the Rx ASIC development team was highly congruent to meeting the commonality objective of the project. Some key cultural attributes of this team were the following; each team member was technically competent and willing to share what they knew with the others on the team as well as willing to learn from the others. There was a culture of fairness and rationality within the decision making process as each developer worked toward the same goal. Each team member checked the others work hence taking responsibility for the whole project not just one piece of it.

4.1.2 Rx ASIC Design Structure Matrix Analysis

The Design Structure Matrix (DSM) given in Figure 19 represents the coupling of development tasks within the ASIC development process and the TTM development process described in section 1.3.4 of this paper. The entries within the matrix provide the coupling of information flow between tasks. Entry (i, j) represents task i as needing input from task j prior to proceeding. The rows therefore show information flow into tasks whereas the columns show information flow out of tasks. As the rows and columns represent the same tasks, a coupling matrix of information flow is established.[50] There are two types of information flow used within the DSM. Entries within the matrix, signified with the number 1, indicate information which is only available when the task generating that information (column task) is complete. Entries within the matrix, signified with the number 2, indicate information which is available prior to the task generating that information (column task) being complete.

There are two coupled blocks identified within the DSM. The first block *"Block 1"* corresponds with the requirements definition phase where there is coupling between activities leading to the approval of the ASIC design specification (DS – DSM Task 3). The second block *"Block 2"*, represents the coupling of internal tasks associated specifically with the development

[50] DSM User's Guide for DSM@MIT, Soo-Haeng Cho, http://dsmweb.org/

of the ASIC (Code Inspection and Simulation Review – DSM Task 15) and tasks associated with the verification of the next higher level of integration containing the ASIC namely the DTRx board, Radio and BTS (System Integrated – DSM Task 31).

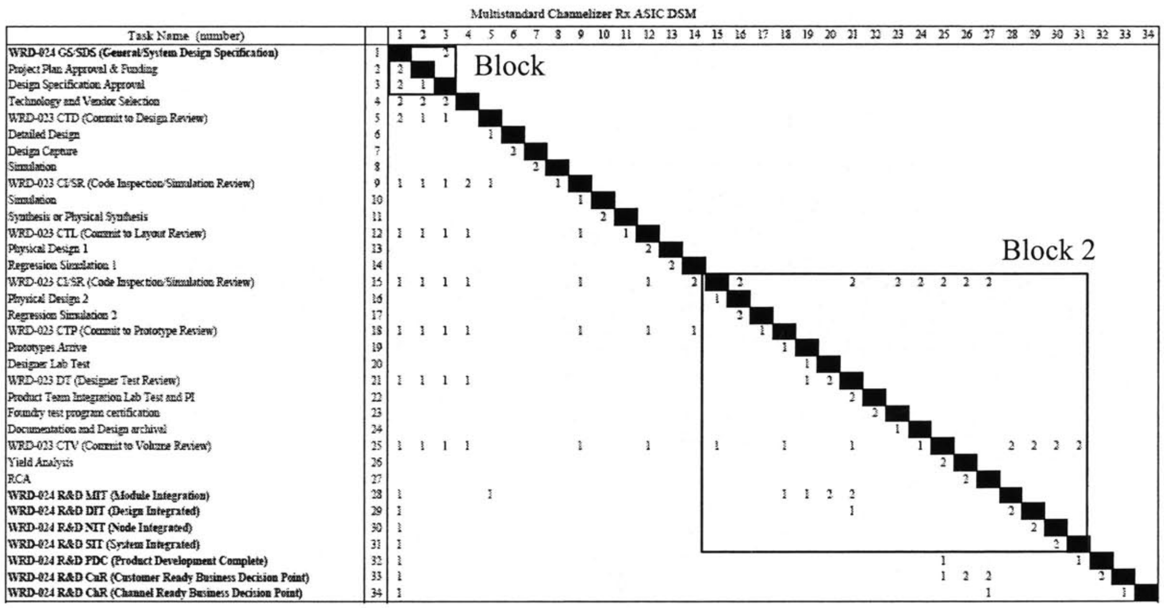

Figure 19 - Multi-Standard Rx Channelizer ASIC Task Based DSM

The major tasks within the ASIC development process are given in Table 4. Estimates of effort and duration of each step are also given with respect to a no commonality strategy between the UMTS and CDMA businesses. Due to the lack of additional data from this time period, exact durations cannot be confirmed. However, the last program status update indicates a close correlation to the estimates given above. Unexpected delays occurred during the Commit to Layout phase due to issues relating to clock skew, insertion delay, and I/O timing issues. As the layout activity is strictly contained within the ASIC development process, there is little evidence to indicate that these delays were impacted by commonality.

Process Step	Description	Relative to no commonality	
		Effort	Duration
Project Plan	In this case this was a multiple month effort aligning the two businesses.	1.5x	3x
ASIC Specification Approval	The ASIC specification (DS) needs to take into account higher level system attributes both the CDMA and UMTS standards.	2x	2x
Vendor Selection	Vendor selection is based on the technology used and is partially dependant on the DS.	1x	1x
Commit to Design	Resources allocated and detailed design begins	1.5x	1.5x
Code Inspection & Simulation Review	First review after completion of simulations.	2x	1x
Commit to Layout	Physical ASIC layout begins determining the size of the die.	1x	1x
Code Inspection & Simulation Review	Second simulation after completion of ASIC layout.	2x	1x
Commit to Prototype Review	Commit to first prototype to be used in ASIC, Board, Module and System verification.	1x	1x
Designer Test Review (ASIC)	Final review of verification data from all levels of system integration	2x	1x
Commit to Volume	Decision to proceed into volume production.	2x	1x
Estimated Total Impact[51]:		1.25	1.3

Table 4 - Rx ASIC Development Process Steps

The second major delay occurred due to commonality as the UMTS system software was not available to confirm the final ASIC design, hence postponing tasks 28 and 31 (Module Integration and System Integration) of coupled Block 2 shown in Figure 19. The impacts of the UMTS system software availability impacted both the ASIC development as well as the CDMA

[51] The estimated total impact of commonality on the ASIC development program is based on a weighted average of each activity

business as they were also depending on the ASIC for their projects. The delay of the system software for UMTS was also a leading contributor to the abandonment of commonality on the DTRx card discussed next.

4.2 Digital Transmit Receive Circuit Card (DTRx)

The Digital Transmit Receive (DTRx) circuit card performs digital signal processing of UMTS and CDMA 3G signals. The card can provide processing for three 2G channels or one 3G channel.

In the forward link[52], the DTRx card receives digital base band data. It performs digital signal processing (DSP) via the on board Tx channelizer ASIC applying pulse shaping, rate conversion, peak limiting, interpolation, frequency shifting, channel combining and other signal conditioning and processing algorithms to the digital base band data. The post processed digital data is then transmitted to a digital to analog converter (DAC) on the transmit receive (TRx) radio card for subsequent up conversion and RF transmission to the mobile user[52].

The DTRx is a printed circuit card assembly found inside the CDMA and UMTS transmit receive module (TRM) commonly referred to as the radio. The assembly is located at the fourth level of product hierarchy shown in Figure 15. A functional block representation of the DTRx printed circuit card assembly showing the RF/IF and digital signal paths is given in Figure 21and Figure 22 for reference.

[52] forward link refers to signals generated at the BTS and transmitted to the mobile users, reverse link refers to signals generated by the mobile user and subsequently transmitted to the BTS

Physically, the part is realized as an industry standard glass epoxy (FR-4) multilayer printed circuit card shown for reference in Figure 20.

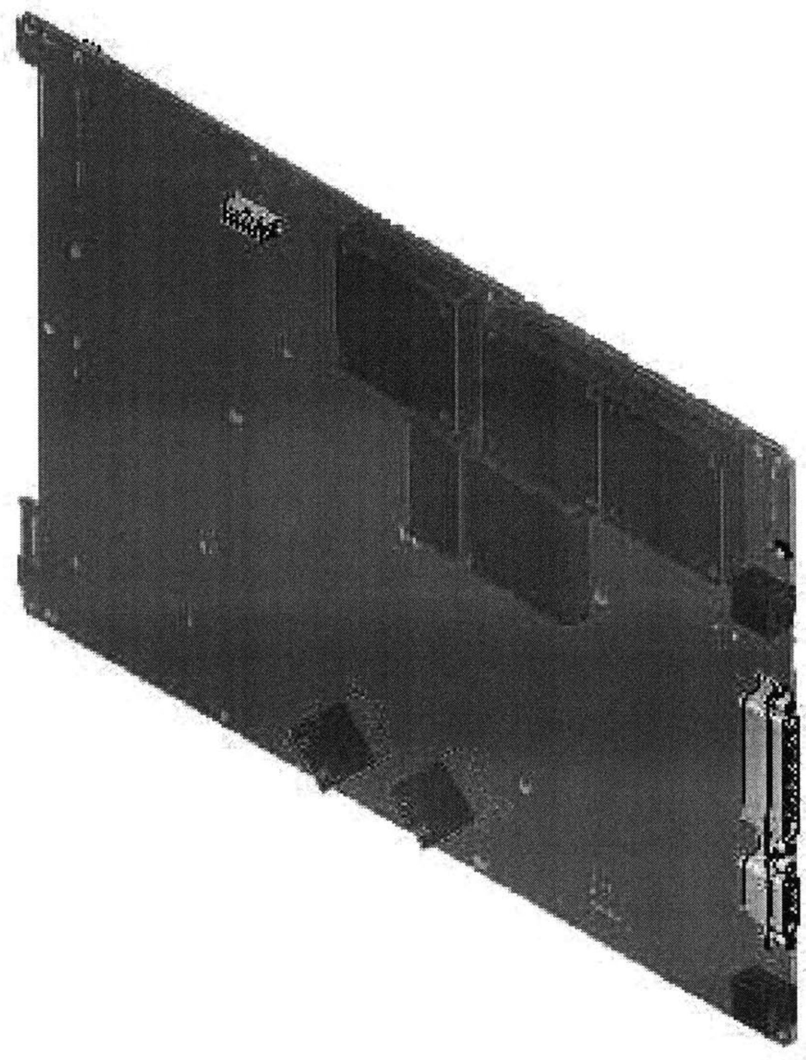

Figure 20 - DTRx Printed Circuit Card Assembly (FR-4) Physical Realization

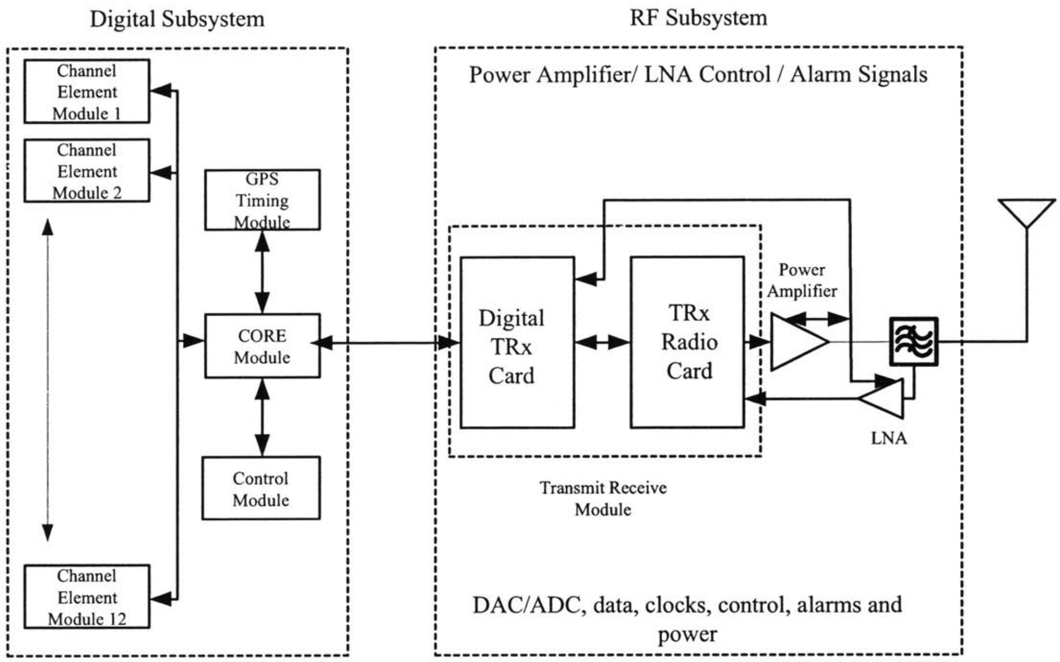

Figure 21 - DTRx Signal Flow within CDMA/UMTS BTS

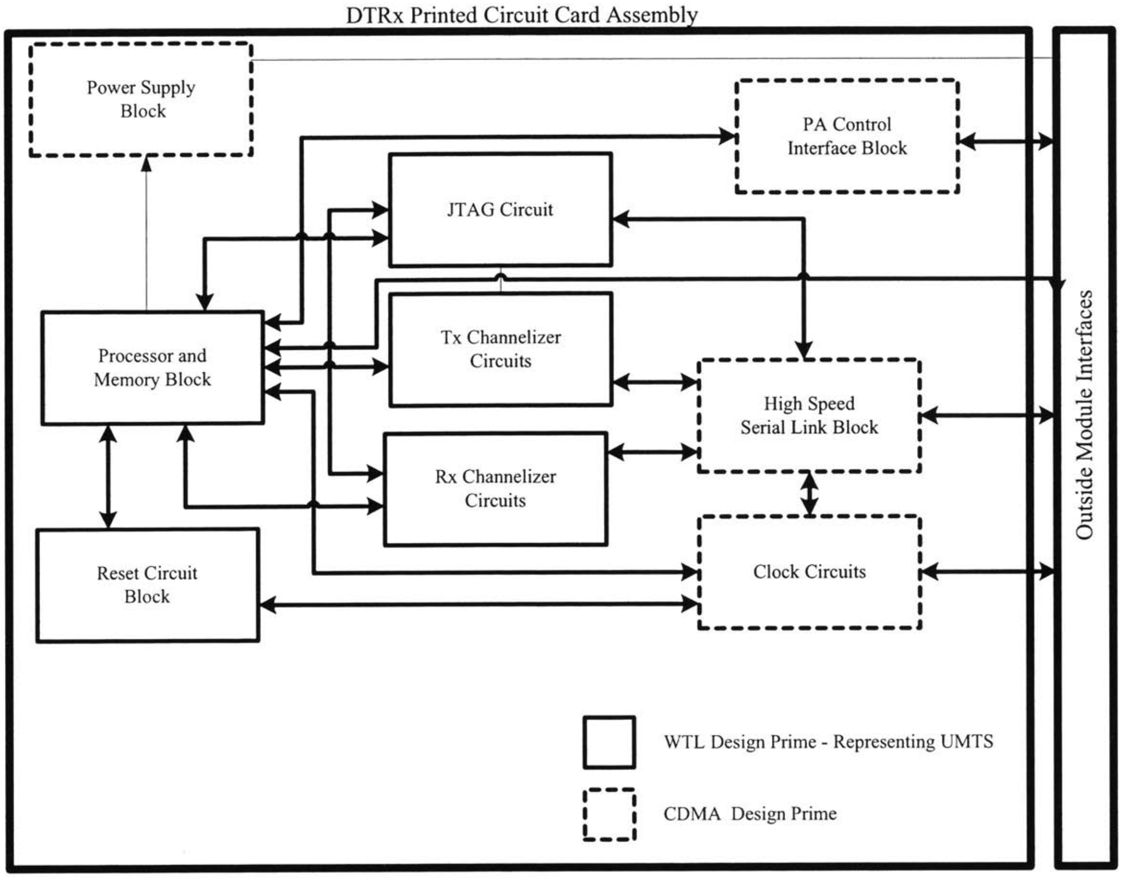

Figure 22 - DTRx Functional Block Diagram

The development of the DTRx card took place at the same time as the development of the Rx ASIC, Tx ASIC and high speed serializer (HSSPC-II) ASIC. As mentioned in the previous three lenses analyses, there are two Rx ASICs, two Tx ASICs and two HSSL ASICs per DTRx card making the ASIC designs and the DTRx design very interdependent of each other. Due to the shortage of hardware development resources within the UMTS business, the WTL development organization was solicited to support the design of a UMTS DTRx card.

Given that the WTL team was involved in both the ASIC development and the DTRx card development, all of the external and internal DTRx interfaces were under the control of a single group. This was particularly important with respect to the high speed serial link (HSSL) interfaces as their implementations were different between the UMTS and CDMA BTSs.

Concurrently, the CDMA organization was also planning to design a CDMA DTRx card specifically for use on their next generation multi carrier radio which was to take advantage of the new channelizer ASICs.

Both the UMTS and CDMA development organizations had the same Vice President at the time, who stated that he wanted to achieve commonality between UMTS and CDMA BTS at the highest level. With this mandate, the CDMA hardware development team joined efforts with the WTL hardware development team to develop a common DTRx card.

"My manager was given a mandate to participate in making the DTRx card common for both UMTS and CDMA. Once I was asked, I participated actively in setting the commonality architecture given the mandate to do so from above."53 – CDMA Design Prime

It was not clear at this juncture that any other considerations regarding the impacts of this commonality strategy had been assessed. The other stakeholders namely PLM, Operations and the Software development groups were not actively involved in making the decision. However,

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[53] January 22, 1999 Nortel Networks organizational announcement, VP of Wireless Mobility Development, assumes responsibility for global Mobility R&D Strategy. He will work with GMs to prioritize R&D projects across Mobility, with a focus on commonality

circumstantial evidence indicates that there was an apparent short term benefit to both PLM and software groups.

"PLM was originally very supportive of the collaborative effort as it gave them access to early prototypes which could be used for software development. Once the early prototypes had been completed, PLM became less supportive of a common DTRx card and began to focus more on the cost of the card." –WTL Functional Manager

The following is three lens analysis of the DTRx development project focusing on the implications of the commonality strategy chosen on product development lead time.

4.2.1 The Three Lenses

The Strategic Lens

The idea of designing a common DTRx card servicing both the UMTS and CDMA businesses was primarily borne out of the development organizations in 1999 in an effort to meet time to market pressures and improve design efficiency. The drive toward commonality between UMTS and CDMA had been stated as an organizational objective by the Vice President of UMTS/CDMA BTS development.

"The two businesses had a single VP who wanted commonality at the highest level in order to reduce cost, improve time to market and make ongoing support easier." – CDMA Design Prime.

Because the WTL organization was working on the Rx Channelizer ASIC, it was known within the WTL organization that it wouldn't be a big stretch technically to share a common digital card between CDMA and UMTS. Initially, the WTL organization focused on providing preliminary technical feasibility, design estimates and cost estimates to the CDMA and UMTS businesses. The development organizations agreed with the recommendation to proceed with a joint development program on the DTRx card as it provided a means to leverage WTL design resources consequently freeing up critical work on the UMTS and CDMA hardware design teams. Both hardware development organizations were also motivated to participate as it was generally felt that it would be cheaper to do the development this way and it would provide the greatest value to the company. It also linked well with their high level functional objective which was to achieve higher levels of commonality between the two product lines.

"The director of CDMA hardware development was told to make it work." – CDMA Design Prime.

The software development organizations within each business were not linked into the strategy as the firmware and higher level software had always meant to be different leaving only the hardware to be common. It is not clear why this decision was made but this lack of linkage with the stated objectives proved to be a crucial juncture in the future evolution of the DTRx card.

CDMA/UMTS PLM organizations were also in agreement to proceed, although, a common development program was not viewed as ideal by either organization. Initially, it was felt that the major benefit of a common development program was to provide early prototypes more quickly. The CDMA PLM team already had a design started, so this was a bit of a bother to them, but they were willing to do multiple hardware spins, driven primarily by their software schedule. The UMTS PLM team, on the other hand, was faced with resource constraints within their hardware development team leaving them with few other options.

The Operations organization was not involved in setting the original commonality strategy although ultimately beneficiaries of it. Once engaged, they quickly became advocates for it but this indicates a poor linking between the commonality objective and the interests of a significant stakeholder during the early phases of the project.

Of the three top business metrics at the time, namely time to market (TTM), time to cost (TTC) and time to quality (TTQ), the common DTRx development project was most heavily aligned to TTM. Commonality was viewed as a way of achieving rapid time to market in particular by the UMTS business. It was also thought that the higher combined volume between the UMTS and CDMA portfolios would ultimately help drive a lower overall product cost, with UMTS primarily taking advantage of the much higher CDMA volumes initially.

The senior managers from the CDMA and UMTS radio design teams were involved providing the technical interface requirements and overall performance specifications for the common DTRx card. Furthermore, the functional managers provided final authority on all technical decisions along with the high level architects from each business who ultimately approved the overall architecture of the board after performing cost and functionality tradeoffs.

The technical teams for both CDMA and WTL (representing UMTS) worked closely together and were located in the same building in Ottawa. The work on the single card was split into blocks. It was then partitioned further into functional blocks. The partitioning of the functional blocks between design primes is given in Figure 23.

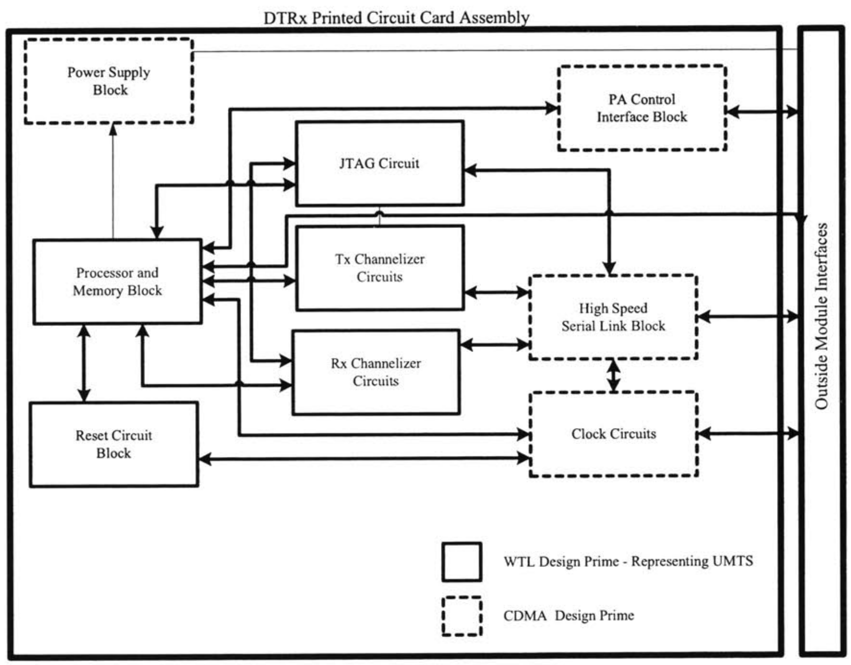

Figure 23 - DTRx Functional Block Development Partitions

At the hardware design level, the UMTS and CDMA design primes created a single Design Specification (DS), schematic and physical layout. Both developers worked from the same single set of design files. Between the two developers, each would check the others work to ensure that their own requirements were being met in the functional block being designed by the other. They were trying to include the other groups' requirements as they designed their assigned functional block using a peer review as the final check and ratification cycle.

According to the developers, the fact that two requirements were folded into one design made the work slightly more complex. Schematics were harder to read due to redundancy. Layouts had to ensure both requirements were met making the design harder to comprehend. The timing analysis done had to be robust enough to work for both applications using the non optimized design caused by commonality. All of these factors have a negative impact on product development lead time and consequently TTM. Also, there are indications that a number of external groups impacted by the commonality strategy on the DTRx card were grossly underestimated. This was compounded by the lack of a formal process to facilitate decision making at the working level when technical differences of opinion came to light. The quote below is a good indication of this.

"I focused on defining the external interfaces. First, this included making sure all external cables and connectors would be used. I had to interface into approximately 20 designers at various levels (mechanicals from both CDMA and UMTS, WTL and even the CDMA radio architect). Everyone had an opinion; it was not very structured for the requirements gathering. It turned out to be a very ad hoc proposal of interfaces." – CDMA Design Prime.

The product development phase most impacted by the commonality strategy chosen was the requirements gathering phase. The artwork layout phase also took longer according to estimates from the hardware designers. Although, the total effort was less than twice which is what would be expected if two separate cards had been developed.

The software for UMTS/CDMA was quite different from the base level up. The CDMA software was developed in Ottawa and the UMTS software was developed in Paris. This added complexity was exasperated by the fact that the UMTS software group would not support the designer verification test (DVT), software needs of the WTL organization or the Test Engineering organization that instead had to rely on the CDMA software team for their DVT software needs. From a commonality perspective, piggy backing test software off a common hardware design turned out to be a beneficial time saving effort. However, additional effort was required to convince the CDMA software team to provide software which would enable testing of unique UMTS functions, something clearly outside of their immediate mandate. At a high level, the program seemed to be structured around the commonality goal but at the working level, it required tremendous effort. Contributing to the increased work load, were the separate software streams which inevitably led to schedule differences between the two businesses. Because of these schedule differences, DVT and regulatory test cycles were disjoint between CDMA and UMTS adding further complexity to the program with respect to maintaining commonality.

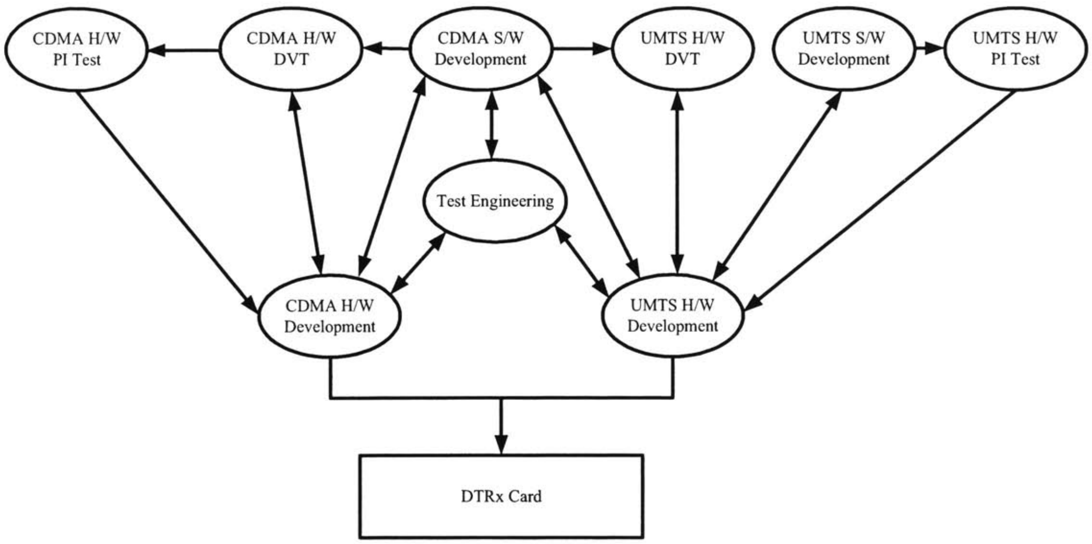

Figure 24 - DTRx Program Structure (Reciprocal, Pooled & Sequential Task Interdependence)[54]

The grouping of activities and the program structure are shown in Figure 24. The diagram shows activity groupings which have pooled, sequential and reciprocal interdependencies, further confounding the efforts to maintain commonality. At this level of assembly, this increased complexity can be explained by the necessity to involve an increased number of external groups involved in the product development process. In particular, the complexities of involving external software development teams and test engineering are evident.

In addition, to the above, is the complexity of a multi-site development environment. As with the Rx ASIC team language differences between Ottawa and Paris, were not considered a significant issue. In fact, there was a preference expressed for working across different time zones as long as immediate information wasn't required. The fact that there were *"fewer*

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[54] James Thompson, 1967, introduced a topology of task interdependence - reciprocal, sequential and pooled.

interruptions" was considered positive as more work was getting done. However, during periods when real time support was required, the multi-site development environment was viewed as cumbersome.

"During hardware integration it became very difficult, duplicate issues popping up simultaneously in multiple locations all requiring real time support." – CDMA & UMTS Design Primes.

Churn requests were handled directly by the individual designing the impacted functional block. Conflicts were escalated to the UMTS and CDMA businesses independently through the functional management organizations, resolution and consensus was based on the two sides calling each other. There was no single person assigned to facilitate conflict. It was strictly based on a best efforts basis.

As an example, the UMTS group wanted to use a Utopia bus which was not standard to CDMA. In order to implement this efficiently, the UMTS organization felt that the brand new Motorola 8260 microprocessor, with the functionality for a Utopia interface already built in, was required. This slowed the project down significantly as only engineering samples of the 8260 were available. These microprocessors had bugs and were a new platform on which the hardware and software developers had little to no experience. Alternately, the CDMA group did not need this higher end processor and could have achieved the required functionality using the Motorola 860 processor (which was slower, cheaper and generally available) and had already been used on the previous generation of CDMA radio.

"Supporting two sets of functionality on one board dramatically increases complexity". – CDMA Design Prime.

Strategically, the initiative was poorly aligned with the TTM, TTC and TTQ metrics of both lines of business. The activities of each stakeholder were not closely linked resulting in additional and unnecessary task complexity. The grouping of activities was also incongruent with the desired output of a common DTRx card, separate software teams, schedules, DVT and PI cycles. All contributed to the ultimate abandonment of the commonality strategy toward the end of the product development cycle.

The Political Lens

In all, there were seven primary stakeholders involved in the development of the common DTRx card. At the highest level, these can be grouped into the WTL hardware development team (representing UMTS), CDMA hardware development team, UMTS software development team, CDMA software development team, CDMA PLM team, UMTS PLM team and Operations. The functional mandates of each of these groups as well as their roles and responsibilities are given in Section 1.3.4 of this paper. At the time of this project, the CDMA business was under tremendous pressure to develop 3G capability within their portfolio and the UMTS business was under tremendous pressure to introduce a new 3G platform.

Resource constraints, within the UMTS hardware development organization, as well as a high level commonality mandate were the underlying reasons for a joint development program on the DTRx card.

A sighted benefit was the belief that a common development effort would yield earlier prototypes which could be used for software development. Software development was viewed as the longest lead item in the push for 3G capability and as such was treated as the critical path by the PLM organization.

Even with a joint development effort, the UMTS development team was forced to solicit help from the external WTL organization which was neither for or against the effort but felt it aligned well with their capabilities. In retrospect, it appeared to be a *"marriage of convenience"* primarily driven by the need of the UMTS business for early DTRx prototypes.

It appears that the net zero-sum, *"pie"*, was altered in favor of the UMTS business to the detriment of the CDMA business in the short term. The decision to proceed could be viewed as irrational[55] by the CDMA business. At the working level, the WTL hardware developer representing the UMTS business was given schedule, cost and quality targets to meet. On the other hand, the CDMA hardware developer was given the mandate to just make it work for both product families.

[55] Irrational in this context refers to decisions made which do not optimize ones own position.

"There were no constraints placed on the project. The mandate was for it to be common. Interfaces although different to each of the Power Amplifiers had to be worked out." – CDMA Design Prime

Once the program kickoff occurred, the hardware developers strictly focused on the execution of the technical aspects of their work. As the UMTS requirements were viewed as more stringent, additional channelizers were added; a more powerful micro processor was used (8260) and the board became more complex than it would have been given a CDMA only solution. Also, the UMTS integration proved to be more difficult. Ultimately, the additional UMTS objectives were met at the expense of CDMA business. Some minor advantages in efficiency were gained by the UMTS business through the doubling up of testing effort with the CDMA business.

Up until the customer ready (CuR) milestone, both PLM organizations were primarily concerned with time to market. Any delays caused by the additional complexity of a common development program were masked by the delivery of the Rx channelizers which ultimately, from a hardware perspective, became the gating items for both UMTS and CDMA. Also, large differences in schedule between the UMTS business and the CDMA business evolved. The DTRx went through PI testing for CDMA long before it went through it for UMTS. At this point, the CDMA business took over the schedule lead. Furthermore, the high level UMTS BTS development program was being gated by software problems as well as problems with other modules. To compound the issue, the pickup of UMTS technology in the market place suddenly stalled, reducing the focus on time to market within the UMTS business. The divergence at the card level occurred very late in the design process (CuR) with the 1W4 common artwork of the DTRx card becoming the specific OD1 artwork for CDMA.

The commonality strategy was quickly abandoned as inequity in business needs became evident. Both teams wanted to isolate themselves from the other teams churn and reduce the management effort required to keep things common. Product cost was sited as the main driver for the spilt. However, two stock lists had always been planned for use in order to optimize the product cost for each business.

Once the commonality strategy had been abandoned formally, the CDMA line of business quickly set about optimizing product cost and rapidly bringing the product to market. Also, the structure of the development organization changed from that shown in Figure 3 to that shown in Figure 4. CDMA and UMTS BTS development was no longer consolidated under one Vice President. Instead, it was split into two groups each reporting into their respective lines of business further weakening the mandate for commonality between the two products.

In summary, when viewing power *"as the ability to get things done, one can better visualize the character of power as a force that is both constraining and producing"*[56] The development organization was the primary benefactors of the commonality as it allowed them to pool resources and meet their commitments to both the CDMA and UMTS businesses. This was primarily done through the control of key technical resources as well as the overall management of the product development process. Typical programs of this nature within Nortel Networks

[56] Ancona, Kochan, Scully, Van Maanen and Westney, 1999, "Organizational Behavior & Processes", Massachusetts Institute of Technology, South-Western College Publishing, Boston MA, ISBN 0-538-87546-1

would have had an independent, integrated project team leader (IPTL) managing execution of all deliverables. As the CDMA PLM organization was primarily concerned with time to market, it was faced with accepting the commonality strategy as a means of getting prototypes more quickly. This turned out not to be the case as the Rx ASIC development program ultimately became the gating item with respect to hardware development for the CDMA business. The UMTS PLM organization had no other options as they did not have adequate development resources within their business. The Operations organization, whom ultimately would have benefited the greatest from a common DTRx, had little formal input or influence into the decision to have a common DTRx card or the subsequent decision to abandon that strategy.

"I influenced the team to get a product which could be tested on a common test bed/fixture with common software. This helped me out greatly in meeting TTM. I tried very hard to convince the team to keep the product common but I didn't succeed. At CuR the PCB was actually still quite common. It was a cost reduction program that completely killed it." – Operations Test Engineer.

As the organizational structure shifted and the individual business needs became more clearly defined, an observed shift in the balance of power was observed transitioning from the functional organization to the individual businesses.

The Cultural Lens

As mentioned in the Cultural Lens analysis of the Multi-Standard Receive Channelizer ASIC, the significant change in Nortel Networks corporate culture came in 1997 with the Right

Hand Turn initiative headed by John Roth. As this has already been previously discussed in great detail, this analysis will focus primarily on the cultural aspects of the organization as it pertained to the development of a common DTRx card.

The TTM culture introduced by John Roth in 1997 dominated the whole project. The culture within the wireless business was described as;

"Very aggressive compared to the digital switching culture within Nortel Networks. Aggressive schedules are a key cultural component (TTM) of the wireless business."–Anonymous

Although the general sense was of speed and effectiveness, new employees to the organization found the culture chaotic.

"I didn't understand the culture. As an outsider, it seemed as if each department worked in their own way. It appeared as things were happening quickly but it was actually very slow. It felt chaotic because I had to learn a lot of new things very quickly." – Operations prime

Each of the groups within the team, had unique subcultures which provided insight into the organization at the time. As mentioned in the multi-standard Rx channelizer ASIC analysis earlier, the UMTS team in France was considered more conservative and more apt to take time to thoroughly analyze data before making a decision. Also, the UMTS organization was described as ASIC centric rather than board centric giving the impression that they were only reluctantly involved in designing the DTRx card. The teams in Ottawa appeared to be more aggressive and apt to take risks for the purpose of accelerating schedule. The WTL hardware development organization was seen as being more interested in technically elegant rather than robust circuit implementations. Manufacturability and reliability were not seen as guiding principles in their decision making process. The CDMA hardware development organization was viewed as pragmatic, typically choosing the more conservative and robust circuit implementations. Between all of the groups, they appeared to have an excellent working relationship understanding and complimenting each others attributes. However, the organization above the working level was viewed as lacking communication between businesses with disjoint priorities and not being aligned to the commonality strategy chosen.

To a large extent, the culture which emerged within the DTRx development team was one of individual effort and persistence. Some key cultural attributes of this team were the following: Each team member worked well with the others, issues had to get worked out as there was no real mechanism for simple conflict resolution and each team member checked the others work taking responsibility for the whole project. There was also an underlying sense of pride that a quality product had been developed in such challenging circumstances and under such schedule duress. This cultural attribute was present in each individual interviewed and appears to be pivotal in the temporary success of making the DTRx card common to CDMA and UMTS.

4.2.2 Design Structure Matrix

There were two simulations performed on the DTRx card development. The first DSM, (DSM 1) reflects the common UMTS/CDMA DTRx card previously discussed in this paper and is shown in Figure 25 in its *"as early as possible"* (AEAP) analyzed form. The second DSM

(DSM 2) reflects a hypothetical development program in which only a CDMA DTRx is developed and is shown in Figure 26 in its *"as early as possible"* (AEAP) analyzed form. The DSM is structured around the information flow outlined in the Nortel Networks PCB[57] design process. The basic PCB development is designed to be iterative as described in Table 5. The durations used in the simulation are based on estimates provided by the developers involved in the project. The estimates provided were normalized in order to protect the proprietary nature of this information. The *"Detailed Design – Block 2"* reflects the tight coupling of activities during the detailed design phase between the two developers. The dependency between functional blocks and hardware developers is shown Figure 23. The coupling between the DTRx card and the Rx ASIC previously discussed is not included in the analysis. The DSM entries use the same nomenclature as those used for the Rx ASIC DSM given in Section 4.1.2.

There are three coupled blocks identified within each of the two DSMs. The first block *"Definition -Block 1"* corresponds with the requirements definition phase where there is coupling between activities leading to the approval of the DTRx design specification (DSM 1 - Task 5 and DSM 2 - Task 3). The second block *"Detailed Design - Block 2"* represents the coupling of internal tasks associated specifically with the development of the DTRx (DSM 1 Task 8 – 17 and DSM 2 Task 6 - 15). The third and final block *"Verification – Block 3"* reflects the close coupling of tasks associated with the five levels of verification employed. Of particular note, is the difference in coupling between the designer test (DT) stage and the functional agreement (FA) stage of the design process. This can be understood as failures are expected to occur during the DT stage and iterations are expected and consequently planned for.

[57] source Nortel Networks – CDMA PCP development process 2000.

Alternatively, unexpected feedback from the later stages of product verification, namely, module, system, node and network levels only feed back to the layout phase of the FA stage.

The impact of strictly maintaining the commonality strategy as modeled in DSM 1 assumes that there are no material or human resource constraints such as software availability. As we are primarily concerned with the implications of commonality on product development lead times, this is appropriate. However, it is important to note that the joint development of a UMTS/CDMA DTRx was abandoned shortly after the completion of design verification testing for the CDMA variant (DSM 1 – Block 3). There were two primary reasons given for this at the time. The first reason was TTM, as UMTS system software was not available at the start of the verification cycle, verification could not begin on the UMTS DTRx variant. The second reason was TTC. There were significant material cost implications to the CDMA DTRx variant directly due to the additional functionality required to support commonality.

"This can also be caused by unexpected market changes or technology innovation in the middle of processes. The unplanned iteration is often regarded as a failure mode and requires managerial decision about whether to continue or abandon the project." [58]

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[58] Author of Users Guide for DSM@MIT describing the impacts of an unplanned iteration

Process Step	Description	Communication	
		Input	Output
Project Approval	In this case this was a multiple month effort aligning the two businesses.	Plan	Funding
Design Review (DR)	Cross functional development team review of the Design Specification (DS) includes systems and software groups.	DS	Updated DS
Design Inspection (DI)	Cross functional development team design review of circuit schematics (CS) and circuit analysis (ANA). At completion a key items list (KIL) and manufacturing stock list (MSL) are generated.	CS, ANA	Updated CS, ANA KIL/MSL
Functional Agreement (FA)	Cross functional review with manufacturing on PCP specific features (SF), common features (CF), component rationalization and optimization report (CROP), KIL and MSL. A design for manufacturability (DFM) report is generated as an output.	SF, CF, CROP, KIL/MSL	Updated SF, CF, CROP, KIL/MSL DFM
Component Placement Agreement (CPA)	Mechanical review prior to final layout and component placement. Includes validation of DFM implementation and analysis review.	SF, CF, ANA and Initial Layout	Updated SF, CF and Layout Files
Physical Agreement (PA)	Final review prior to build.	SF, CF, Layout Files, ANA and FA milestone minutes	Updated Layout Files and build EC
Build EC	Prototype Build		Prototypes
Designer Test (DVT)	Design verification test using agreed to verification plan (VP). Outcome is a verification report (VR).	Prototype VP	VR re-design if required
Design Close (DC)	Final project close including update of all documentation and release to production.	data set	Updated final data set.

Table 5 - DTRx PCB Design Process Steps[59]

[59] See Appendix 1 for details of how this process was implemented into the DSM model.

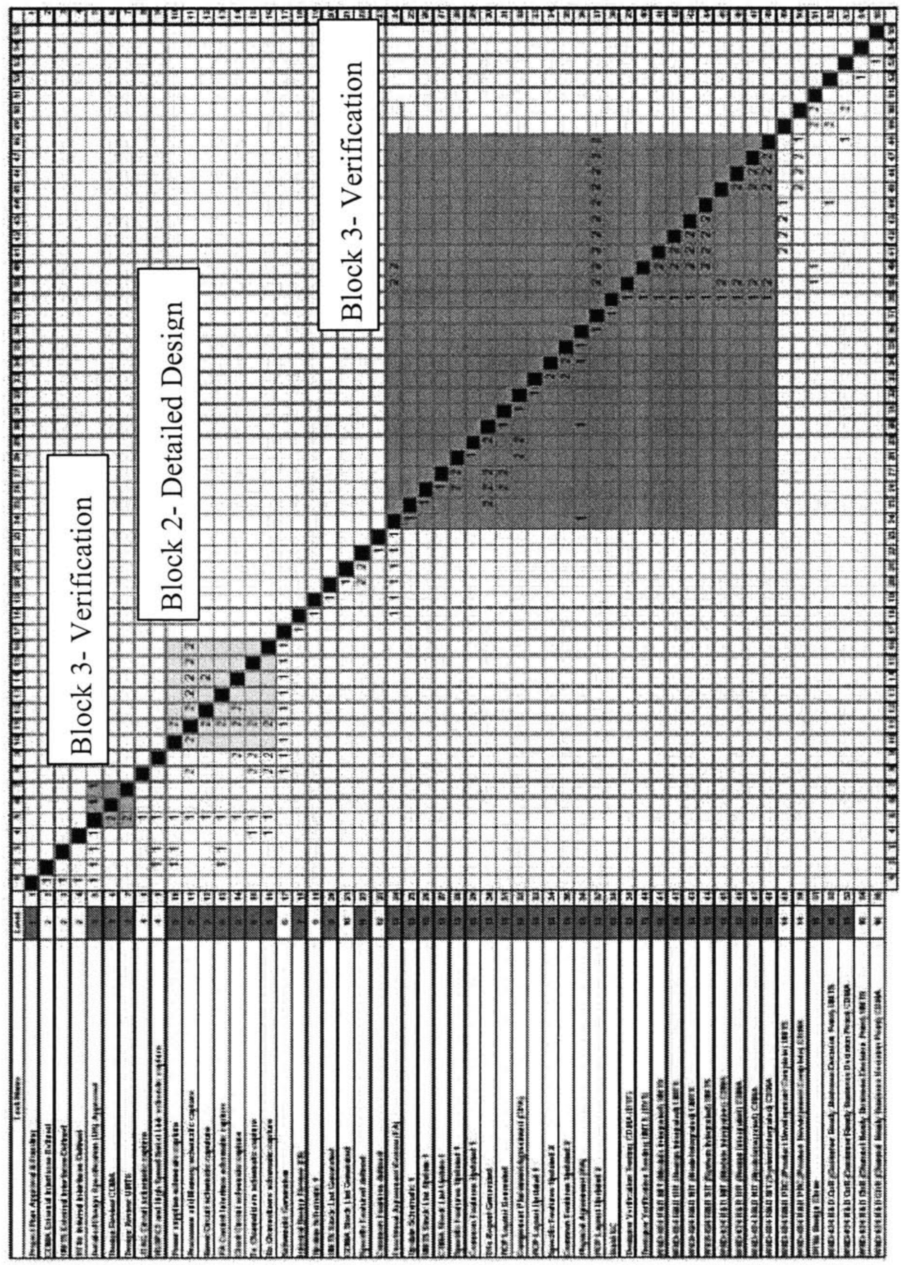

Figure 25 - Joint CDMA / UMTS DTRx Task Based DSM AEAP (55x55)

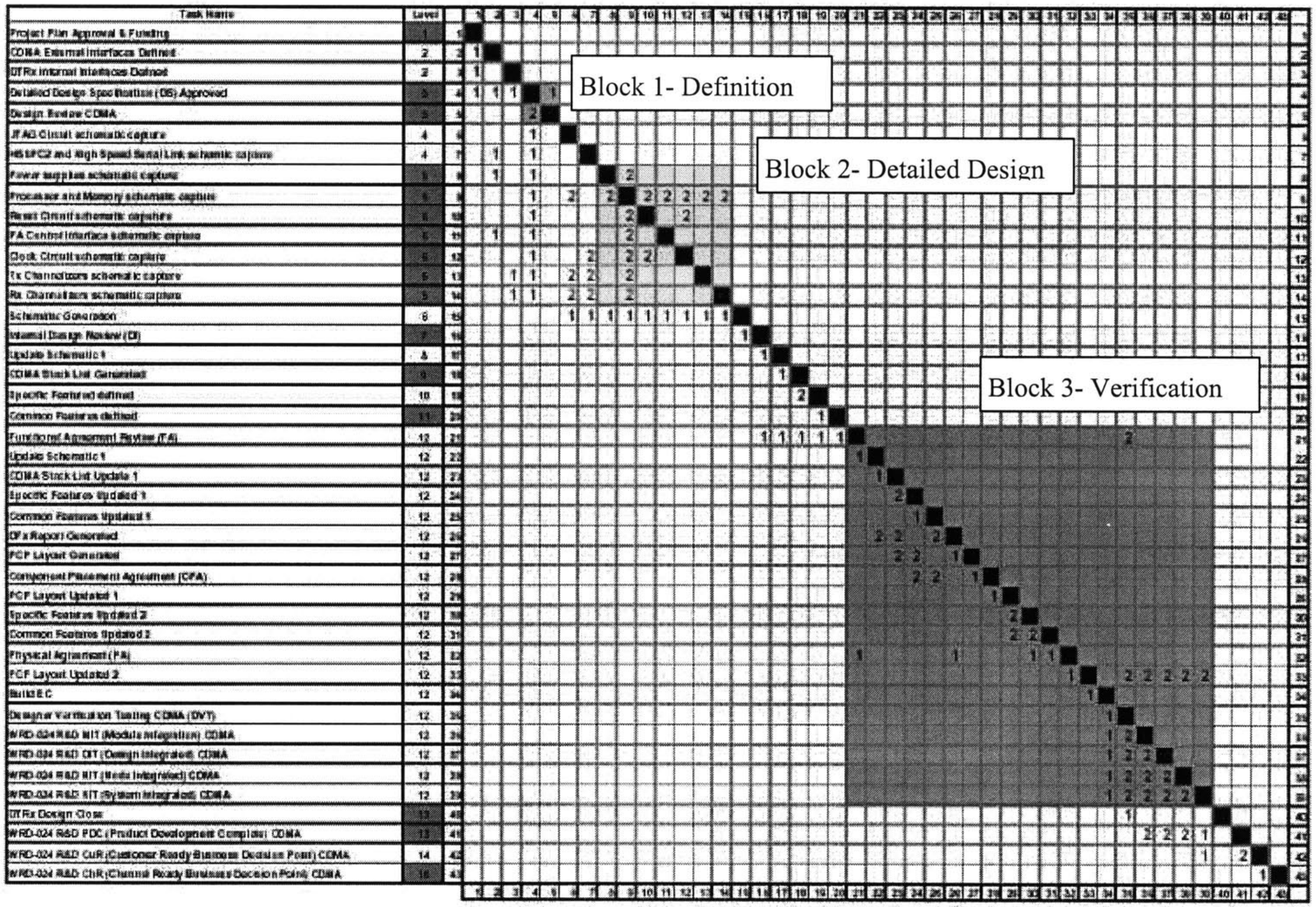

Figure 26 - Hypothetical CDMA only DTRx Task Based DSM AEAP (43x43)

The results of the DSM analysis indicate approximately 28% difference between the coupled UMTS/CDMA development program and the fully autonomous hypothetical CDMA development program. A T-Test of the resulting data indicates a significant statistical difference between the two cases with > 99% confidence interval. A comparison of for each coupled block and complete estimated program duration is given in Table 6.

Block Name	UMTS / CDMA Lead Times[60]			CDMA Only Lead Times[60]		
	Fastest	Average	Slowest	Fastest	Average	Slowest
Block 1 – Definition	.5	.7	.8	.4	.5	.6
Block 2 – Detailed Design	73.7	92.2	113.1	50.3	64.1	81.1
Block 3 – Verification	66.7	78.5	89.3	51.9	62.2	70.8
Total Program Duration	μ = 173.8, s = 17.5 Confidence Intervals: (10%,30%,50%,70%,90%) = (156.6, 168.7, 175.1, 182, 193.5)			μ = 113.1, s = 11.9 Confidence Intervals: (10%,30%,50%,70%,90%) = (100, 109, 114, 119, 156)		

Table 6 - Simulated Product Development Lead Times for DTRx

[60] Normalized lead time units

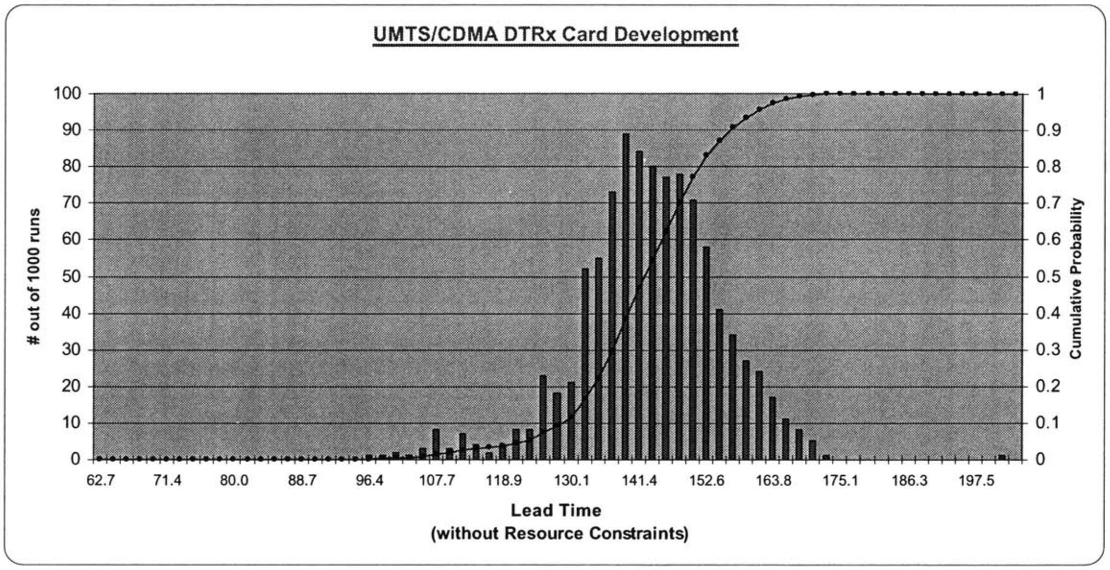

Figure 27 - Simulated Development Lead Time UMTS/CDMA DTRx

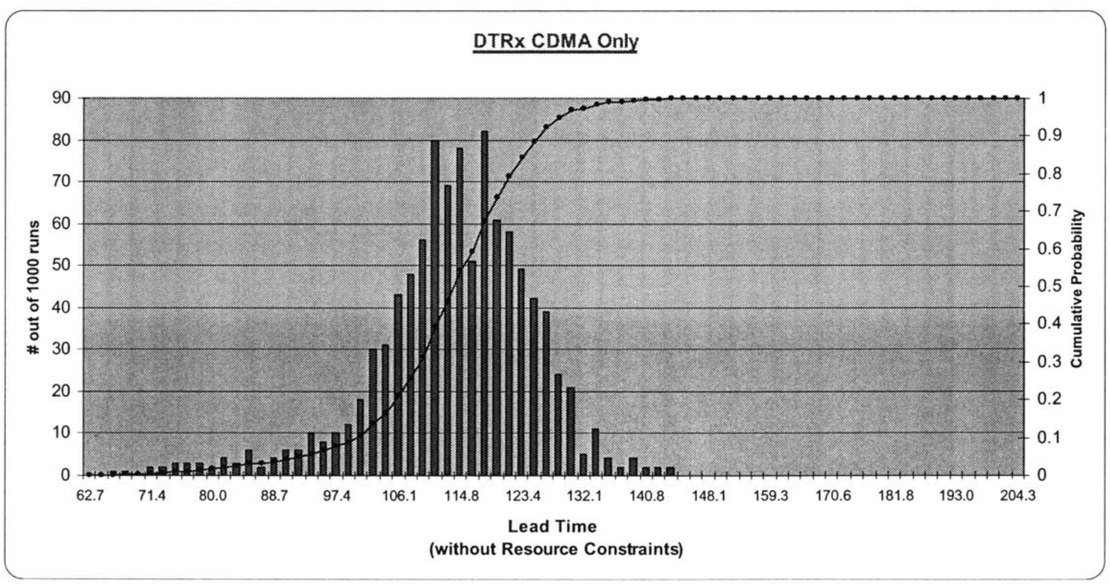

Figure 28 - Simulated Development Lead Time CDMA Only DTRx

4.3 The Common Radio Module (CRM)

The Common Radio Module (CRM) contains all of the functionality of the Rx ASIC and DTRx card previously described in sections 4.10. The additional functionality, contained within this module, pertain primarily to analog RF signal conditioning including amplification, frequency conversion, attenuation, filtering and RF output power monitoring and adjustment associated with the air interface of a CDMA BTS.

In the reverse link, the RF signal from the mobile is received at the BTS antenna and routed to the Rx input of the CRM. The signal is then filtered, amplified and down converted from radio frequency (RF) to intermediate frequency (IF), transformed into a digital signal via an ADC and passed through DSP circuitry similar to that previously described for the DTRx card.

The CRM is a field replaceable unit (FRU) which can be installed on the BTS at the factory or ordered separately for subsequent capacity expansion in the field. The assembly is located at the first level of product hierarchy shown in Figure 13 for reference. A functional block representation of the CRM showing major internal assemblies is given in Figure 29.

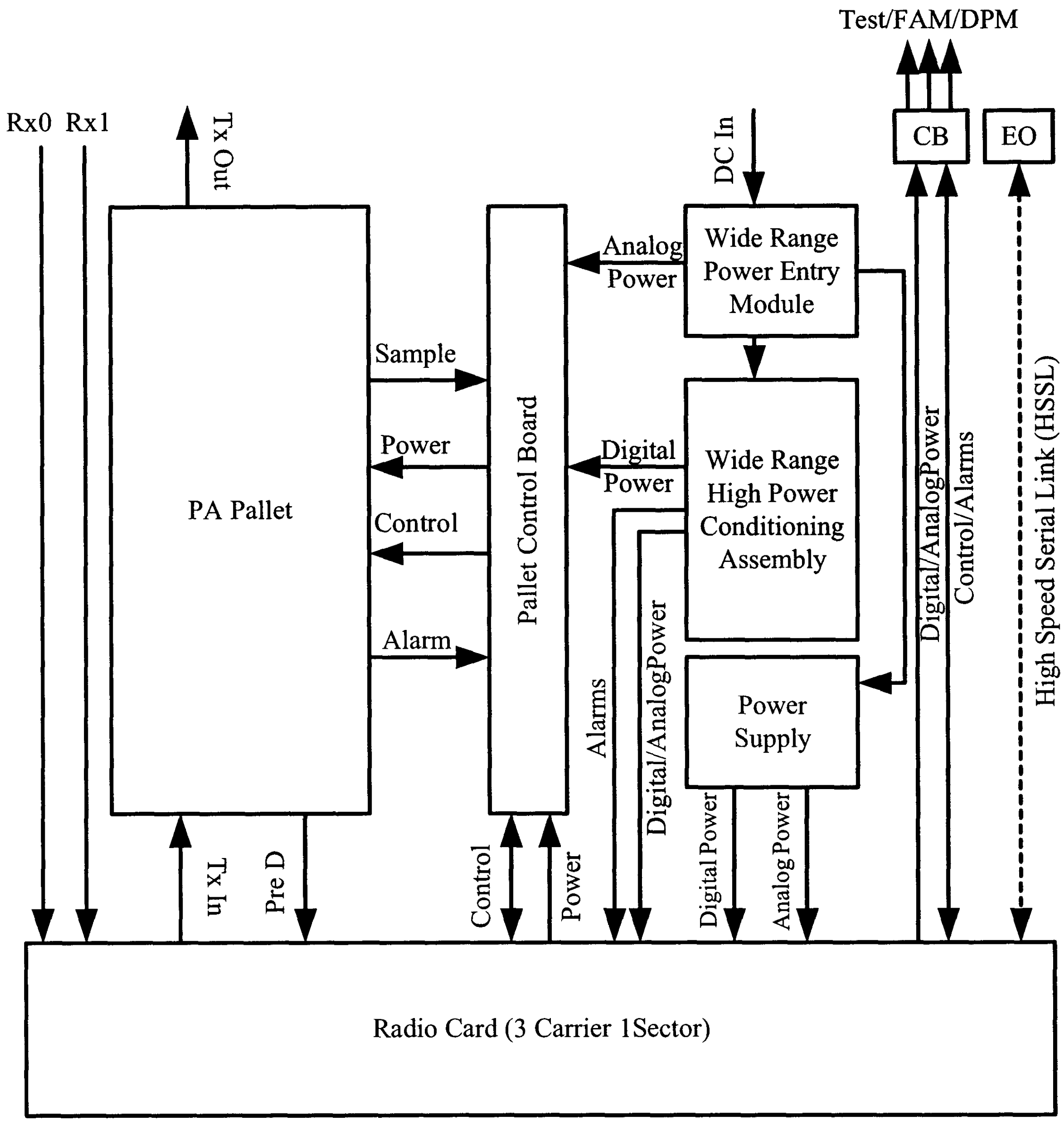

Figure 29 - CRM Functional Block Diagram

Physically, the part is realized as the mechanical assembly shown in Figure 30.

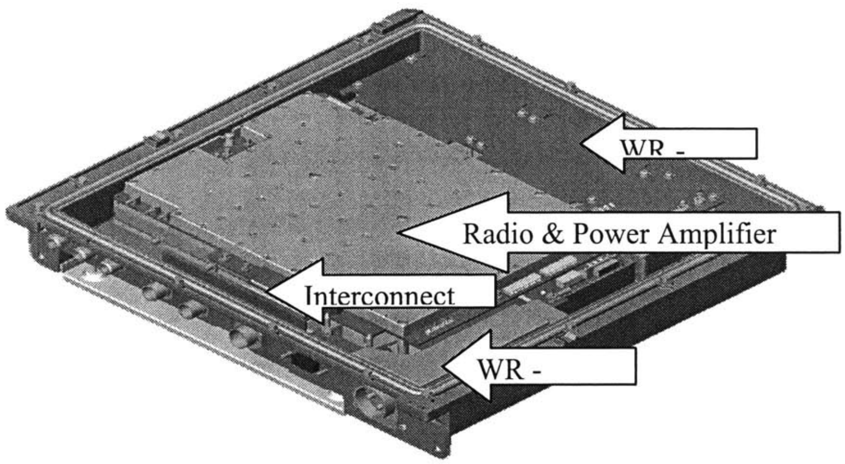

Figure 30 - CRM Physical Realization

The development of the CRM began just after the telecommunications bubble burst in 2001. The module contains the previously mentioned multi standard channelizer ASICs. The module was required to be backward compatible with the existing CDMA product portfolio and therefore shared mechanicals with the existing power amplifier module. Electrical interfaces were previously defined by the DTRx card which is located within the existing multiple carrier transmit receive module[61] (MTRM). Also, the RF performance and call processing performance of the CRM had to be at least as good as or better than the current radio product. The TTM product development process outlined in section 1.3.4 of this thesis was used during the development of the CRM.

[61] The DTRx card is located inside the MTRM module and defines many of the external electrical interfaces of the system.

The program was initiated by the CDMA hardware development organization as a means of improving product cost through the elimination of non-integrated OEM assemblies within the existing radio portfolio. It was felt that by integrating functionality material, handling and manufacturing costs could be reduced. Expected ancillary benefits were improved reliability, performance and a reduction in return rates.

4.3.1 Three Lenses

The Strategic Lens

The CRM is a customer orderable item, often referred to as a field replaceable unit (FRU) within the industry. As such, the product must be introduced using the TTM process given in Section 1.3.4. In all, there were three TTM teams developing six CRM variants during the time of this study. Each TTM team operated autonomously but when required used *"partnership agreements"* to manage program interdependencies.

TTM Program Team	Development Location	Frequency Variants MHz	Mechanical Variants
CRM	Calgary	800, 1900	Metro Cell, international
cBTS	Calgary	800, 1900	Radio Module
Market Capture	Ottawa	450, 2100	Metro Cell

Table 7 -CRM Programmatic Interdependencies

Within the CRM TTM core team, there were four functional stakeholders, representing Development, Operations, Service Introduction and Product Line Management. The role of the

New Product Program Manager and the Core Team Leader was to ensure that the program delivered against its commitments to the business.

The commonality strategy for the CRM was originated by the senior management of the development organization.

"We were trying to leverage multiple applications off of a common artwork, primarily to meet Time to Market criteria with our limited resources." – Senior Development Manager.

The lead architects and functional managers within the development organization set strategies for PCB commonality across all applications and platforms as well as frequencies. This was the result of multiple discussions with the detail hardware designers who were responsible for the physical implementation of the commonality strategy. Once the strategy had been set, it became very difficult for other stakeholders to influence or change it.

"I did not set the strategy I was strictly managing the design deliverables into the program manager. When I joined just after BR[62] *and all the plans and commitments had already been set." – CRM core team Product Development Manager.*

By design, the TTM core team is highly cross functional in nature. Each core team representative works with their broader functional organization to ensure project deliverables are met. However, even with the cross functional representation, the implications of the

[62] BR – TTM process terminology for Business Ready – Business Decision Point see Figure 6 - Phases of TTM Product Development Process

commonality strategy to the program was not well understood by the core team. It was also apparent, that the implications of commonality with respect to higher levels of assembly weren't fully appreciated within the Development organization. This resulted in module and system level configurations which weren't able to cope with the coupling of multiple common variants at the early stages of the program.

At a high level, the strategy was communicated to all stakeholders. The strategy was also documented within the development schedules, engineering changes, and verification plans all indicating a high degree of design re use. Most of the work fell onto the radio card hardware design groups. They had to intertwine schedules between frequency variants. The Product Development Manager (PDM) had to take detailed schedules and work them into the higher level program plans. The software was structured in order to take advantage of the common portions of the hardware through modularization.

The core team had to stage the overall high level plan in order to manage the extra schedule complexity required to achieve commonality. This added directly to project management overhead. Operations had to set up product codes and overall infrastructure to support commonality.

In order to maintain commonality at the working level, a single board prime was made responsible for both the 800 MHz and 1900 MHz radio card variants.

"I was the detailed designer who was trying to implement the stated commonality objective, namely, to design four boards on one layout." – 1st CRM radio card development prime.

The requirements for both 800MHz and 1900MHz were defined in parallel before any detailed design began. This included the frequency block design and level analysis which were completed but not implemented until later in the program. The roles and responsibilities of the designers also changed. Each designer was now responsible for delivering functional blocks for both 800MHz and 1900MHz variants. In effect, each engineer owned a piece of the commonality requirement.

Co-location was also another key measure in maintaining commonality. By focusing all the development work, into one group, in one location, effectively ensured commonality at the PCB level. When a second development team was engaged to work on the 450MHz variant, the AW diverged. One explanation for this is the fact that the 800MHz and 1900MHz were in the midst of significant design churn at the time and it was more expeditious to decouple the AW.

"There was a foundational data set which all other design groups were supposed to use as a basis for their work. However, discipline required to maintain the foundational data set wasn't maintained as the various design groups found they lost their flexibility. This behavior was primarily driven by the fact that project needs weren't being met." – CRM core team Supply Chain Operations.

Other organizations, such as test engineering, were also organized around commonality; a single owner for radios and for PA's. However, a significant issue in the grouping and linking of activities was the use of three distinct TTM core teams. The cBTS and 450MHz and CRM programs all had conflicting priorities. Based on findings from a lessons learned session, it was found that the core team leaders didn't relate to each others problems even though they were the same.

"I don't think there was any linkage at all. If I was attending a cBTS meeting, nobody cared about CRM. I felt that I was the only person in the room who seemed to care or know about other product variants. We imposed linkage at the working level as we were the only ones who could see it." – Test Engineer.

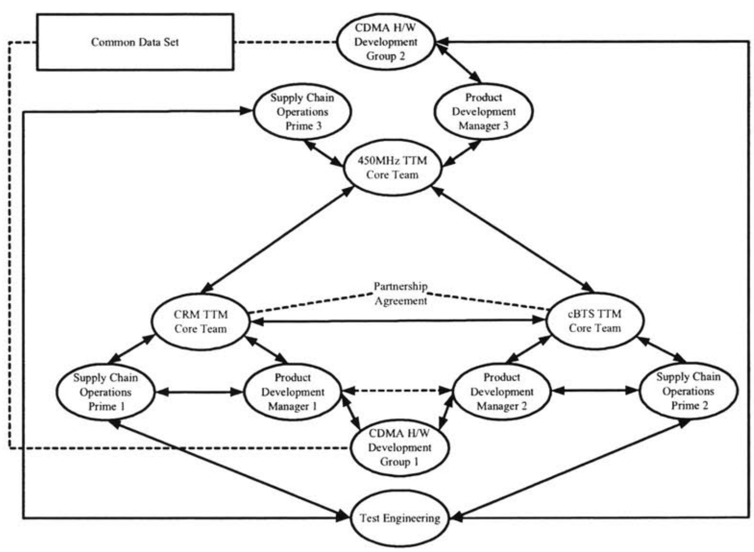

Figure 31 - CRM Program Structure (Engineering) Showing Reciprocal Interdependence[63]

[63] James Thompson, 1967, introduced a topology of task interdependence - reciprocal, sequential and pooled.

The grouping of engineering activities between the various programs simultaneously using the CRM data set is given in Figure 31. The groupings indicate a high degree of reciprocal interdependence. Feedback from the functional design managers indicates that the commonality strategy was adhered to as much as possible. From their perspective, commonality was viewed as an overriding objective, a means by which to achieve TTM for the program.

The original design plan was to use an iterative approach. It was felt that this would reduce risk and protect the program schedule. The plan was to start with the 800MHz variant first then use it as a basis for the 1900MHz design. Changes implemented during the development of the 1900MHz were to be folded back into the 800MHz design hence maintaining commonality. During this process, the development team struggled with implementing non optimum solutions for the sake of maintaining commonality. Performance hits were accepted in order to choose parts with a common footprint for both frequency variants. In certain cases, new hybrid foot prints would be designed to accommodate special items such as the RF ceramic filter, Tx modulator and the LNA hybrid. In many instances, these hybrid solutions never made it into the final product. Radio board partitioning was also crucial, the development team was grouped into specific functions such as digital, IF, Rx and Tx. The digital and IF sections were deemed to be frequency agnostic and therefore most of the development effort focused on making the Rx and Tx RF chains common between variants. However, the use of non optimum circuit implementations for the Rx and Tx RF chains proved more challenging than expected.

Although the original plan included two design iterations, commonality in conjunction with requirements churn, significantly increased the complexity of the development activity and consequently increased the product development lead time.

"Churning in changes during the CRM 1900MHz caused multiple delays. Also, the introduction of the cBTS LNA caused a perfectly functional Rx chain to be modified. We had to squeeze the already tight design by 20% to make it fit. This really threw things off." - 1st CRM radio card development prime.

Under normal circumstances, the commonality strategy would have been abandoned in order to achieve TTM. In this instance, due to resource constraints within the development organization, commonality was enforced through organizational structure and subsequently negatively impacting TTM for the first variant.

There was no explicit or direct linkage between TTM, TTQ or TTC and the commonality strategy. It was implicitly assumed to be beneficial. Shorter design cycles were planned based on commonality assumptions but were never explicitly linked to the high level program metrics.

Strategically, grouping the radio development under one program would have significantly helped align already tightly linked activities with the high level TTM, TTC and TTQ metrics. The negative impact on TTM for the CRM program was offset by later gains in TTM on the cBTS program.

"The fact that we were going through layoffs at the time also helped as it reduced the number of engineers working on the program. Even though the result looked quite structured, in actuality, we lucked out." –2nd CRM radio card development prime.

The Political Lens

In all, there were four primary stakeholders involved in the development of the common radio module (CRM). At the highest level, these can be grouped into the TTM core team leaders (CRM, cBTS and 450 MHz/2100 MHz), PLM, Development and Operations. The functional mandates of each of these groups, as well as their roles and responsibilities are given in Section 1.3.2 of this paper. At the time of this project, Nortel Networks was in a period of contraction. All lines of business were faced with layoffs, salary freezes, cutbacks and general corporate wide cost containment initiatives.

As mentioned earlier, the program was initiated by the CDMA hardware development organization as a means of improving product cost through the elimination of non-integrated OEM assemblies within the existing radio portfolio. It was felt that by integrating functionality material, handling and manufacturing cost could be reduced. Expected ancillary benefits were improved reliability, performance and a reduction in return rates.

The Development organization felt that they were in the best position to deliver the CRM and proposed to do so out of a single location. The underlying reasons given to justify this position vary, however, maintaining work within the organization was certainly a key factor. The PLM organization was on the other hand strictly interested in value to the business and was weighing the benefits of funding an internal development effort vs. funding an existing original equipment manufacturer (OEM) for the development effort.

The Development organization signed up to extremely tight time lines, very low product cost targets and limited development costs. This ultimately swayed the PLM organization away from pursuing an OEM solution for the CRM and funding for the internally developed CRM began. The development organization had effectively singed up to schedule and cost targets which could only be met through high degrees of commonality. Unfortunately, the assumption that commonality at the lower level would not impact higher level integration, turned out to be wrong.

Subsequent schedule pressure from the various core team leaders put constraints on the degree of commonality that could be achieved. Unfortunately, the assumption that commonality at the lower level would not impact higher level integration turned out to be wrong. The TTM core team leaders viewed commonality as something the development organization wanted and not something of direct benefit to them. Therefore, any perceived impact due to commonality on, quality, cost or schedule resulted immediately in pressure to diverge. As programs progress through the product development process, the importance of TTM, TTQ and TTC change. Typically, TTM is the most important metric between the BR[64] and CR business decision points. The influence of TTM diminishes as TTQ becomes more dominant, typically between the CR and ChR business decision points. Toward the end of a program, after the ChR business decision point, TTC (product cost) typically dominates.

[64] Figure 6 - Phases of TTM Product Development Process

Due to schedule and priority conflicts between the three top level programs, the Development Organization had no choice but to diverge from their originally stated commonality strategy. The strategy changed from a common artwork to separate artwork to once again common artwork by the end of the program. Additional frequency variants were also added. The commonality strategy changed to accommodate the triple constraints of all other projects. The implications of the commonality strategy also impacted Operations who became a larger and more influential stakeholder in programmatic decisions. This became particularly evident during the implementation, deployment and life cycle phases. During the implementation phase the 450 MHz, 2100 MHz and cBTS requirements arose. Because of the commonality constraints, they all had to be churned in together. During the deployment phase, the backward compatibility between new variants and the common pieces of the old variants had to be taken into account before deploying the new variants. Once deployed into production, the cost reduction cycle started. This was hampered by the requirement that all variants had to be considered instead of each individually. At the CR business decision point, the role of the Operations core team representative changed from being a project manager to program manager and a layer was added below them to manage the complexities of commonality.

It is apparent that the commonality strategy was not aligned with the priorities of the core team leaders. However, the core team leaders quickly became aware of the implications and the necessity of maintaining the commonality strategy and struck partnership agreements between programs in order to mitigate the situation.

"Both IPTL's[65] would have had the most to loose without a commonality strategy as there wasn't enough development resources available to do both projects independently. If there wasn't any commonality the Development organization would have had to acquire additional resources. Which, in the given business environment was highly unlikely" – CRM Core Team Leader.

It also became evident that the commonality strategy wasn't just *"a nice to have"* for the Development organization but rather a business necessity.

"It was an incredible amount of work just before we went ChR on it. It got worse as we went along. As there were more AW spins it got to the point that it almost became un-manageable. I became a single point for all the activity and it was very stressful. It was a mental battle just to keep on top of the issues for each product." – 2nd CRM radio card development prime

In summary, the traditional positions of decision making and influence within the organization were altered. The business environment and the commonality strategy forced the organization to collaborate, both formally, through the use of partnership agreements between programs and informally, at the working level.

The Cultural Lens

The CRM program started as a single site, single group program shortly after the *"tech bubble burst"* in 2001. Nortel Networks was going through down sizing; reductions in

[65] IPTL – Integrated Product Team Leader, the formal name for core team leader.

development spending and an overall business slow down. Employees within the development organization were worried about losing their jobs. This led to a sense of needing to commit to programs of high risk which provided high degrees of cost reduction. In retrospect, it is well known that the positives of doing the project were emphasized, no negatives were mentioned and the original schedules were embellished to suit the business needs.

"When we started on this program it was a "get on with it tough luck" attitude within management as we were in the middle of layoffs. There was very little emphasis on stroking your ego as they used to do before. It was a complete flip from only two months before." – CRM Developer

Further evidence of a cultural shift occurred during the budgeting process for the CRM program. The design estimates (DE's) were pushed from the top down rather than soliciting input from the bottom up. No *"buy in"* was solicited from the individual designers which was a significant departure from the previous norm.

There was a feeling that the organization was less collaborative during this period. However, contradictory evidence also exists from external organizations indicating that the Development organization was more collaborative than ever. This can partly be attributed to the fact that resource constraints forced functional managers to work more closely to get their work done. However, at the working level employees began to focus exclusively on their own deliverables and this may have led to the observation that the environment was less collaborative.

There is also an acknowledged culture of firefighting; activities are typically started before a rigorous plan can be struck. The preferred project management style is to fix things on the fly. The culture within the organization at the start of the program was significantly different than it was toward the end of the program.

Tensions existed between the different stakeholder groups. For instance, PLM thought the Development group was slow, not thorough and prone to make mistakes. The Development team felt that PLM would ask for everything and deliver very poor requirements. Operations felt that Development was always late on their EC's and they were often wrong or incomplete. Development felt that Operations didn't provide adequate first level troubleshooting on issues.

However, based on those interviewed, they all felt that the culture always led to open and frank communications between groups. Issues were typically addressed at the lowest levels of management. In general, the culture on the team was described as collaborative.

"One thing that I thought was great was that people continued to work together even though they had a disagreement." – CRM Product Development Manager

For instance, two traditionally adversarial groups, Development and Test Engineering, collaborated closely on CRM to the benefit of both parties and the program. Approximately half way through the program, there were changes at the most senior levels of the Development organization. The culture within the development team changed significantly as a result. The new culture was once again much more inclusive.

"The new management asked you how long it would take you to do something and then hold you to your commitment. I felt more responsible as a stakeholder and therefore more accountable for the outcome." –CRM Developer

The culture changed from being highly risk prone and best efforts based[66], to one in which there was increased personal accountability, more control, heavy use of metrics and a better balance between quality, cost and time to market. The other cultural differences between the Calgary and Ottawa sites, previously described in this paper, also existed at the time but as the two teams were working in relative autonomy, the interaction between the two sites has been left out. Of significant note however, the functional management of the development organization traditionally located in Calgary moved to Ottawa half way through the program at the same time as the other major management changes took place.

Throughout all of the interviews, the sense of pride in the accomplishment of producing the CRM and all its subsequent variants was consistent across all functions involved.

4.3.2 Design Structure Matrix

There were four simulations performed on the CRM module development. The first DSM (DSM 4) reflects a CRM module for which four variants are developed simultaneously[67] using the Nortel Networks TTM product development process. Unlike the previously discussed CRM development of this paper, there are no unplanned iterations or resource constraints

[66] This was commonly referred to as an "Entrepreneurial" culture by the employees and was viewed as positive.
[67] See Appendix 2 for details of how this process was implemented into the DSM model.

included in this analysis. However, the model does force commonality to occur at the following DSM 4 task steps, Design Review-Task 19, Block Merge-Task 28, Alpha Design Complete-Task 47-50, Beta Design Complete-Task 71-74 and Product Development Complete Task 79. DSM 4 is shown in it's *"as early as possible"* (AEAP) analyzed form in Figure 32. The second DSM, (DSM 1), reflects a hypothetical development program in which only a single CRM variant is developed. DSM 1 is shown, for comparison, in it's *"as early as possible"* (AEAP) analyzed form in Figure 33.

The DSMs are structured around the information flow outlined in the TTM development process described in Section 1.3.4 of this paper. The TTM development process has three major phases for hardware development commonly referred to as Prototype, Alpha and Beta. The durations used in the simulation are based on estimates provided by the developers involved in the original CRM project. The estimates provided were normalized in order to protect the proprietary nature of this information. The *"Detailed Design – Block 2"* reflects the tight coupling of activities during the detailed design phase between the two developers. The DSM entries use the same nomenclature as those used for the Rx ASIC DSM given in Section 4.1.2.

There are three coupled blocks identified within each of the two DSMs. The first block *"Block 1 - Definition"* corresponds with the requirements definition phase where there is coupling between activities leading to the approval of the CRM for all four variants. The second block *"Block 2 – Detailed Design"* represents the coupling of internal tasks associated specifically with the development of the CRM prototypes at the functional block level. The tasks for Block 2 converge on tasks Merge Blocks and Schematic Capture. The third and final block

"Block 3 - Verification" reflects the close coupling of tasks associated with the five levels of verification employed. Of particular note is the coupling at late stages of the verification process back to the Update Schematic Task. This represents a *"quick turn"* loop in which *"barnacles"*[68] may be added to an assembly manually rather than forcing the product back through its Beta cycle again.

Although the CRM program was originally envisioned as executing as modeled in the DSM, in reality six unplanned iterations occurred. As mentioned previously, commonality was temporarily abandoned in order to expedite portions of the program. The implications of abandoning the commonality strategy meant that although the 800MHz M2 CRM was the first to market, it was also the last to be folded back into the common artwork strategy of the CRM.

[68] "barnacle" – industry term used to represent manually applied modification.

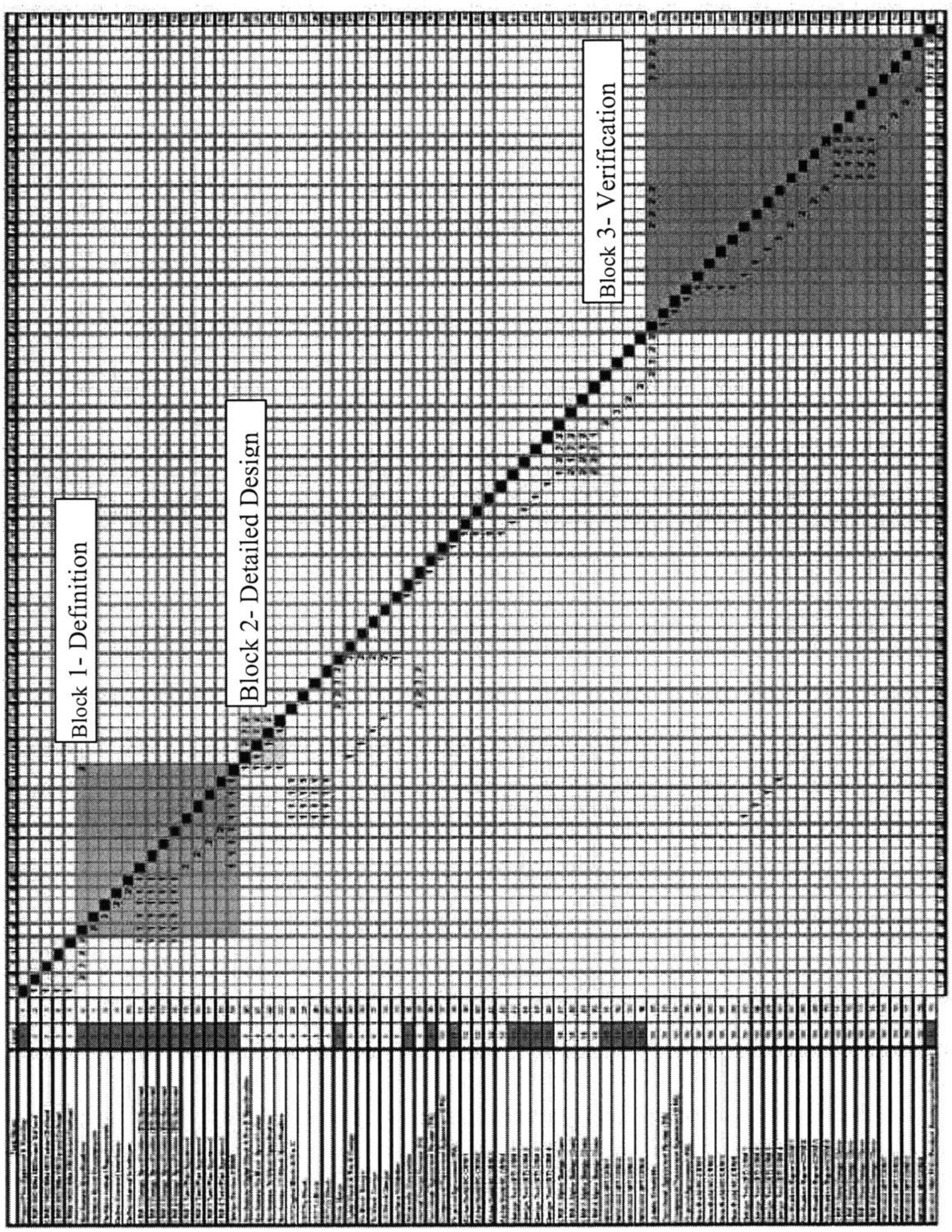

Figure 32 - CRM Four Variant Development with Forced Commonality Task Based DSM (79x79)

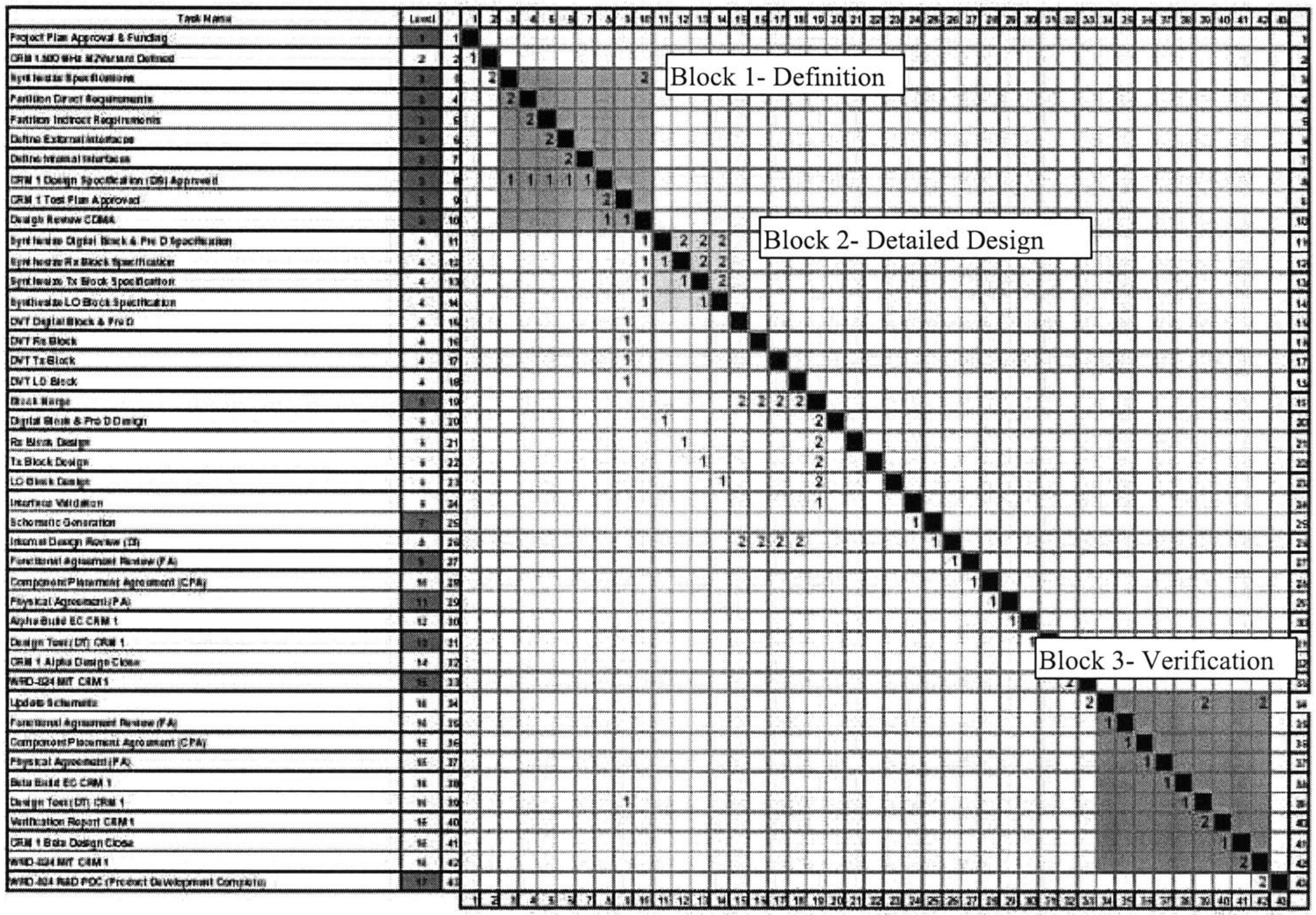

Figure 33 - CRM One Variant Development Task Based DSM (43x43)

The results of the DSM analysis show a 23% difference in the mean lead time between the simultaneous development of four CRM variants versus one CRM variant. A comparison for each coupled block and complete estimated program duration is given in Table 8.

Block Name	Average Lead Times[69]			
	Four Variants	Three Variants	Two Variants	Single Variant
Block 1 - Definition	56.7	57	56.3	52.8
Block 2 – Detailed Design	61.4	63.1	62.9	62.7
Block 3 - Verification	72.5	70.2	66.2	59.2
Total Program Duration and Confidence Intervals	$\mu = 188$ s = 14.5	$\mu = 178.2$ s = 15.5	$\mu = 167.3$ s = 17.9	$\mu = 153.9$ s = 20.8
	(10, 30, 50, 70, 90) % = (173, 183, 190, 195, 203)	(10, 30, 50, 70, 90) % = (156, 175, 180, 186, 194)	(10, 30, 50, 70, 90) % = (141, 161, 171, 178, 186)	(10, 30, 50, 70, 90) % = (129, 140, 151, 169, 180)

Table 8 - Simulated Product Development Lead Times for Multiple Variants of CRM

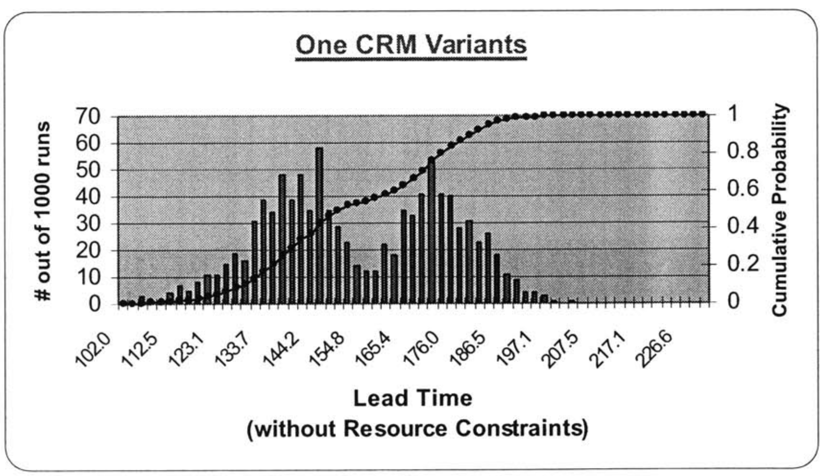

Figure 34 - Simulated Development Lead Time One CRM Variant

[69] Normalized lead time units

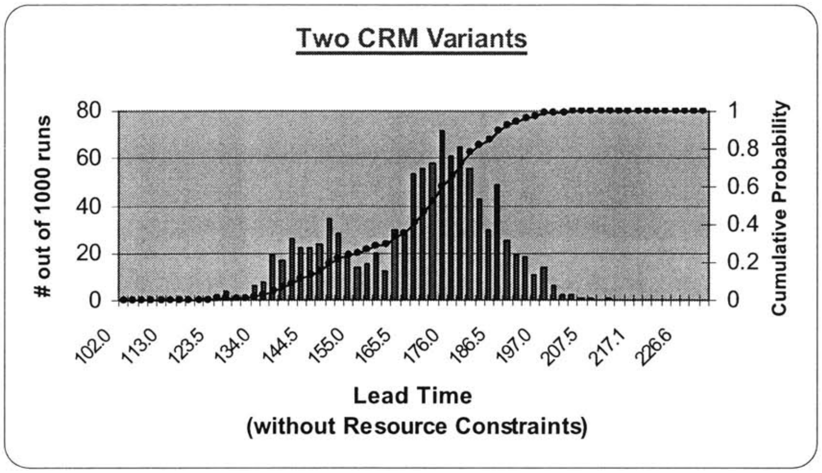

Figure 35 - Development Lead Time Two CRM Variants

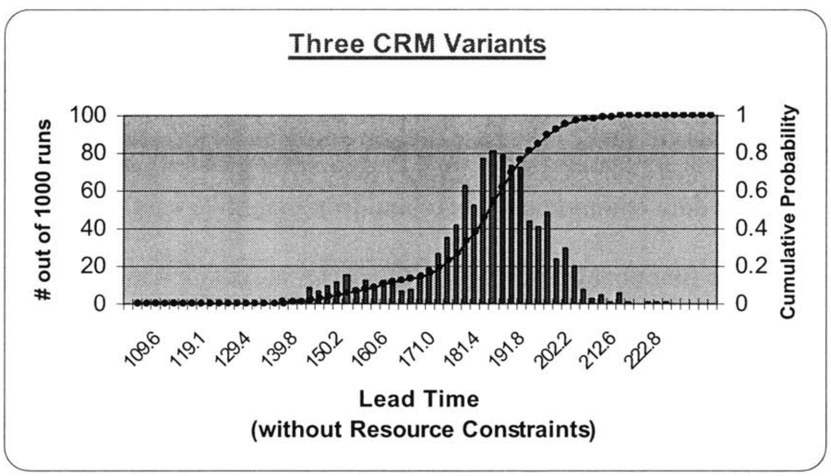

Figure 36 - Development Lead Time Three CRM Variants

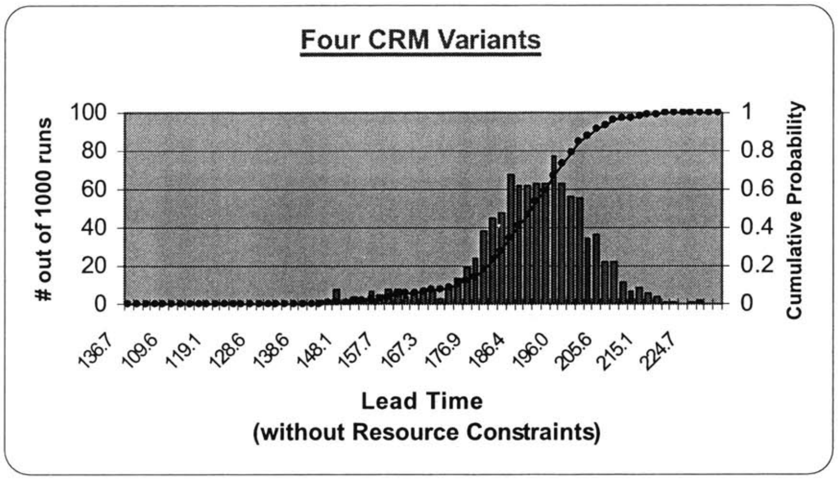

Figure 37 - Development Lead Time Four CRM Variants

4.4 Base Transceiver System (BTS)

The compact BTS (cBTS) is a CDMA 3G base-station capable of supporting a 3 carrier, 3 sector deployment[70]in a single shelf. The base-station contains all the required functionality to process wireless voice and data communications to and from a mobile user. A description of the functionality of each major functional block within the cBTS is provided in Table 9. A high level functional block diagram of a typical Nortel Networks CDMA BTS is provided in Figure 38 for reference. The system is a mechanical assembly which utilizes a modular bus architecture, the physical realization of the system is shown in Figure 39. The cBTS is the top level assembly located at level 0 of the product hierarchy shown in Figure 12.

[70] One CDMA carrier is capable of supporting up to 22 voice calls, sectors refers to antenna orientation.

Major Module	Function	Common
T1 Interface Module (TIIM)	Provides protection for the T1/E1 transport network interfaces.	Yes
Customer Configurable Alarm Module (CCAM)	Supports multiple customer configurable alarms, a shared GPSTM, fan tray alarm monitoring and input DC voltage monitoring.	No
GPSystem Timing Module (GPSTM)	The GPSTM interfaces with the GPS antenna and provides the main timing signal to the rest of the system.	Yes
Control Module (CM)	Provides system control and packet switching and routing, also interfaces with CORE module on legacy systems.	Yes
Channel Element Module (CEM)	Performs all of the vocoding, spreading and de spreading associated with CDMA signal processing.	Yes
Radio Module (FRM, MFRM, CRM)	Tx and Rx RF signal conditioning including amplification, frequency conversion, attenuation, filtering and output power monitoring.	Yes

Table 9 - Description of cBTS Functional Blocks

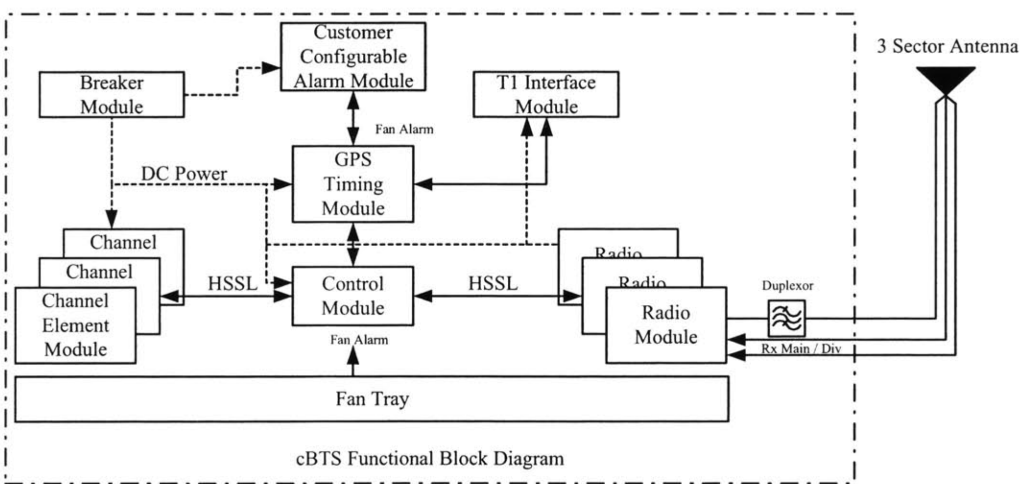

Figure 38 - CDMA cBTS High Level Functional Block Diagram

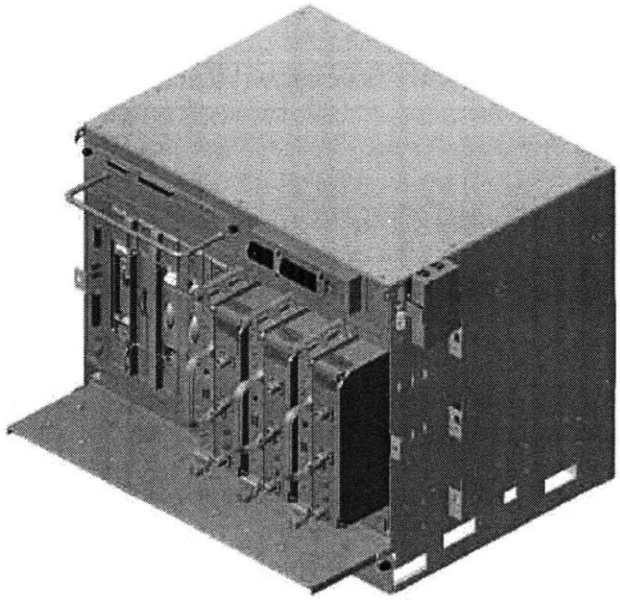

Figure 39 - cBTS Physical Realization

The cBTS platform was conceived of a simple, cost effective entry level BTS specifically targeting markets in developing countries. The development program focused primarily on reducing product cost through the elimination of non-integrated OEM assemblies, removal of non essential functionality, increased functional integration through the use of a more integrated bus modular architecture[71]. As with the CRM, it was felt that by integrating functionality, reducing material handling and manufacturing effort a cost benefit could be achieved. Expected ancillary benefits were: improved reliability, performance and a reduction in return rates. The PLM organization placed one significant commonality constraint on the program; all high value digital modules had to be common with the existing Metrocell[72] platform. This was to protect

[71] Ulrich, Karl T. and Eppinger, Steven D., 2000, "Product Design and Development", 2nd Ed., McGraw-Hill Co., Boston, ISBN 0-07-229647, p185
[72] Metrocell is a Nortel Networks trademark and refers to its main line of CDMA BTS.

existing customers from carrying extra spares inventory and to minimize the design effort, especially with respect to software on the new cBTS platform.

The technical prime made proposals based on the constraints placed on the design team by the PLM organization to keep the digital modules the same, effectively forcing commonality to the Metrocell platform. This commonality requirement at the highest level of assembly ultimately drove churn into existing development programs such as the CM2 and CRM program previously discussed.

4.4.1 The Three Lenses

The Strategic Lens

As a new platform introduction, the cBTS required significant architectural definition. This work began well in advance of the formal development program. The PLM organization, Development organization and Marketing were the key stakeholders in the early part of the program where the commonality strategy was first established.

"Because of the strategy chosen, there was a lot of work that occurred before SR. This was the biggest chunk of work with the System Design Specification and the High Level Design documents. After SR had been achieved on the project the work load dropped off significantly" – cBTS Architect.

Once high level agreement had been reached, the architecture and commonality strategy between cBTS and Metrocell was communicated to the broader team. The digital modules were to be common with the Metrocell in order to ease the business transition onto the new cBTS platform. The new RF module commonality was assured by having the CRM development team develop a radio for both Metrocell and cBTS. Software commonality was assured through hardware commonality and the desire to maintain one software stream for the cBTS.

"The fact that we had common software was absolutely critical to the R&D saving achieved." – cBTS Architect.

As the cBTS is a customer orderable system, it must be introduced using the TTM process given in Section 1.3.4. There was only one TTM team developing the cBTS and all its core members were co-located in one site. As there were many dependencies between subordinate programs *"partnership agreements"* were used to co-ordinate deliverables. Notably, the *"partnership agreement"* between the CRM program and the cBTS program proved particularly challenging.

Within the CRM TTM core team, there were four functional stakeholders, representing Development, Operations, Service Introduction and Product Line Management. The role of the New Product Program Manager and the Core Team Leader was to ensure that the program delivered against its commitments to the business. The cBTS development team was formed around the Nortel Networks TTM model shown in Figure 5.

Linking of subordinate activities occurred as high level specifications and detailed design documents became ratified by the broader organization. Lower level activities became aligned and synchronized with the high level system development effort. The grouping of activities and the program structure is given in Figure 38. The figure indicates a high degree of reciprocal interdependency between activities not unexpected at this level of assembly. Due to the layering of TTM programs, the complexity and interaction between individuals at the working level were not directly visible. The majority of work for the cBTS core team leader involved juggling the higher level schedule.

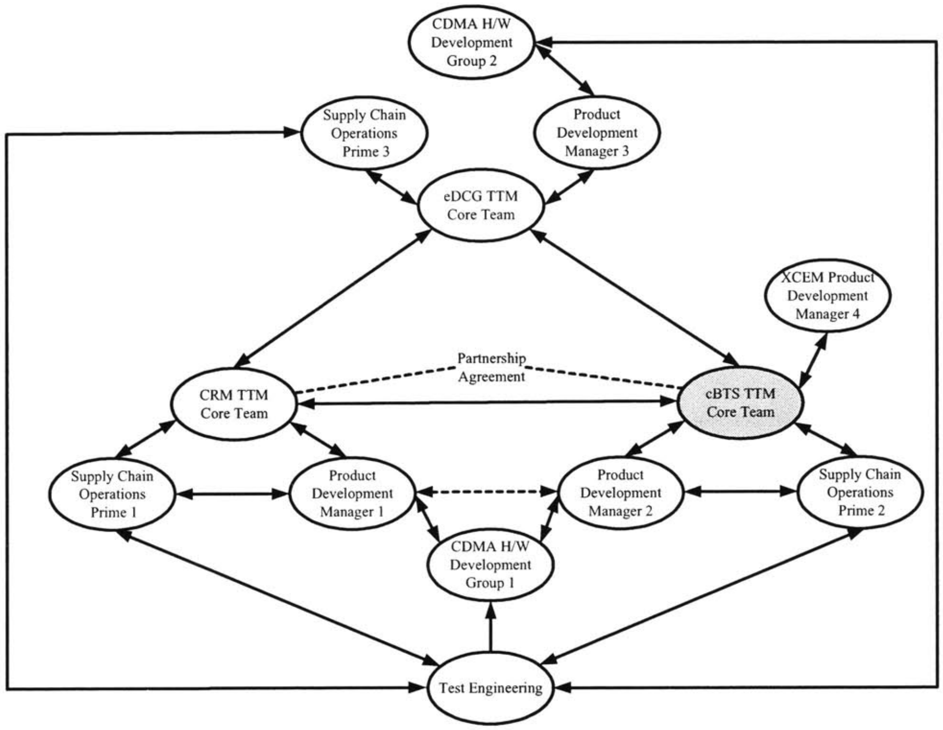

Figure 40 - cBTS Program Structure Showing Reciprocal Task Interdependence[73]

[73] James Thompson, 1967, introduced a topology of task interdependence - reciprocal, sequential and pooled

"No major problems were encountered. Multiple groups were involved which is inevitable on any project regardless of commonality. The XCEM 192 which was designed by the Ottawa group was partitioned as a complete unit (black box). The amount of re-use on cBTS actually made it easier to work between sites." – cBTS Architect

At this level of assembly, there appeared to be excellent alignment to the high level business metrics TTM, TTC and TTQ. The commonality strategy chosen helped to focus and align activities to the top level metrics. Ultimately, more commonality was achieved than had originally been planned. The commonality strategy remained in place for the complete duration of the program indicating that good grouping, linking and alignment of activities had been achieved.

The Political Lens

The PLM organization and the Development organization were the two primary stakeholders. The majority of decision making and direction setting for the program occurred prior to the SR business decision point, effectively limiting the dialogue to these two groups.

Cost and Time to Market conflicted most with the commonality strategy. Higher degrees of commonality in the digital group would have extended the project and consequently cost more money. Quality was already benchmarked against the existing product.

The Development organization wanted lower development costs and the PLM group wanted more commonality to assist in market acceptance. Once agreement was reached, the

Development Organization performed an analysis whose sole purpose was to optimize Development benefits first. This included minimizing variance between legacy products, schedule risk and the ability to be able to verify, at system level, very early on in the project. The Development organization also optimized their resource profiles and reviewed the long term technical benefits of the program. Once this work had been completed, the plan was sent out for review to the broader group of stakeholders such as PLM, Operations, Marketing and the Product Cost group.

"I was the judge and jury. I stated my opinion first and then challenges could be made after the fact." – CDMA Hardware Development Director.

In summary, the high level direction for the cBTS program was agreed to between the two major stakeholders. Primary considerations were customer acceptance, product cost and product quality. Being able to quantify these against the existing BTS platform helped both stakeholders agree on a commonality strategy which would benefit both organizations and ultimately the customer. As the degree of commonality was quite high, input from other stakeholders was viewed as less crucial.

The Cultural Lens

The cBTS program was generally viewed as portion of the natural and necessary evolution of the existing Metrocell BTS portfolio. As such, there was much debate in regards to the systems ultimate form. During the initial product definition meetings, the pervasive culture was one of consensus building.

"Indecisiveness during project launch and concept stages up to MR, we tried to "boil the ocean". We are afraid to make a decision and then review it later for mistakes or adjustments. There is an apparent lack of trust early on in a project based on biased opinions not objectives." – CDMA Hardware Development Director

The frustration with the consensus building was primarily found at the management level. Outside of the management organization, the culture was seen as entrepreneurial and fast paced, similar to that of a start up.

"It felt like a more agile environment as we only had one decision maker and we did not rely on committees to make decisions. We also had a smaller team in place."- cBTS Architect.

A parallel observation was made on the CRM program. The organization has a culture of consensus based decision making. Although it appears to be slow to those involved, once a decision is reached, there is 100% alignment by all stakeholders in doing whatever it takes to get the job done.

As with the other programs studied, subtle subcultures existed within each functional group involved. One observation cited the differences between the hardware development team and the software development team. The software team was viewed as being more conservative whereas the hardware development team was viewed as being prone to take risks. Another observation cited the differences between the PLM and Development groups as one in which each of the parties often felt that role reversals took place.

5 RESULTS

5.1 The Three Lenses

The results indicate a strong correlation between commonality and the triple constraints of TTM, TTQ and TTC. The data gathered through multiple interviews for this thesis, indicates that an imbalance between TTM, TTQ and TTC metrics drives away from achieving commonality. The most significant driver was found to be TTM. This was the case in the early stages of the CRM program and the later stages of the DTRx program. On the cBTS program, the scope of the development activity was limited to re using existing modules. This commonality constraint was primarily driven by the need to meet TTM through re use. The second most significant driver was found to be TTC. In several instances, when there would have been additional costs added to the product due to commonality, the requirement was quickly abandoned. This was observed on all four projects studied. Interestingly, the Rx ASIC, which technically, has no cost associated with extra functionality, has extra unused functionality built in. The least significant driver was found to be TTQ. This is partly attributable to the ingrained Nortel Networks quality culture in which high quality is considered a given.

The implications of TTM, TTC and TTQ also became evident in situations in which there was poor alignment of project objectives. In all of the projects analyzed, poor alignment with all of TTM, TTC and TTQ resulted in less commonality.

The three lens's analysis also showed that organizational structure, although important for the purpose of alignment to objectives, was not as important as a structure to arbitrate conflict. This was specifically seen on the Rx ASIC and the DTRx card.

The results of the three lens's analysis are shown graphically in Figure 41, a description of the axis is provided in Table 10.

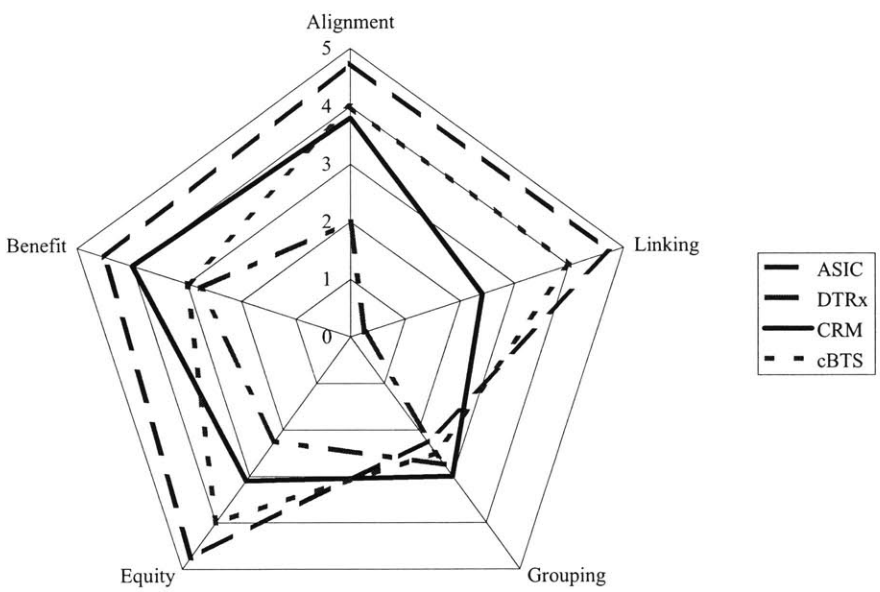

Figure 41 - Three Lens's Analysis Summary Plot

Axis Name	Description	Scale Interpretation
Alignment	Degree of alignment between the commonality strategy and the business objectives of the other stakeholders.	Scale 0 Poor Alignment …5 Excellent Alignment
Linking	Degree of linkage between the commonality strategy chosen and the top level metrics of the product namely quality, cost and time to market.	Scale: no linkage 0…..5 tight linkage (commonality was a top level metric)
Grouping	Impact due to organizational structure resulting from the implementation of the chosen commonality strategy. (multiple groups, multiple sites, different languages, time zones)	Scale: low to no impact to work due to organizational structure 0…..5 high impact to work due to organizational structure.
Equity	Degree of equity between stakeholders during development phase with respect to impacts arising from the commonality strategy chosen.	Scale: no consideration of equity 0…..5 high consideration for equity between stakeholders.
Benefit	Degree of benefit derived from the commonality strategy chosen.	Scale: detrimental 0, 3 neutral, 5 beneficial.

Table 10 - Three Lens's Plot Axis Description

5.2 Design Structure Matrix

The DSM analysis indicated that there was far less impact to product development lead time than originally thought. Between different levels of assembly, there appears to be less impact at the higher levels of assembly as can be seen in Figure 42.

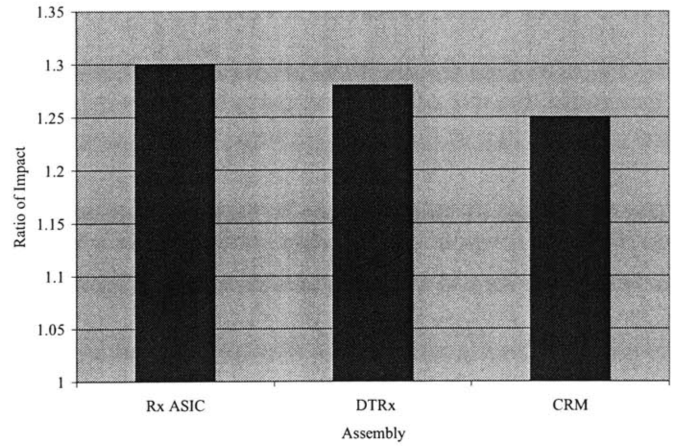

Figure 42 - Impact of Commonality vs. Level of Assembly

The increase in product development lead time, with respect to the number of parallel variants being designed, is given in Figure 43. There appears to be a marginal increase in development time as more variants are added.

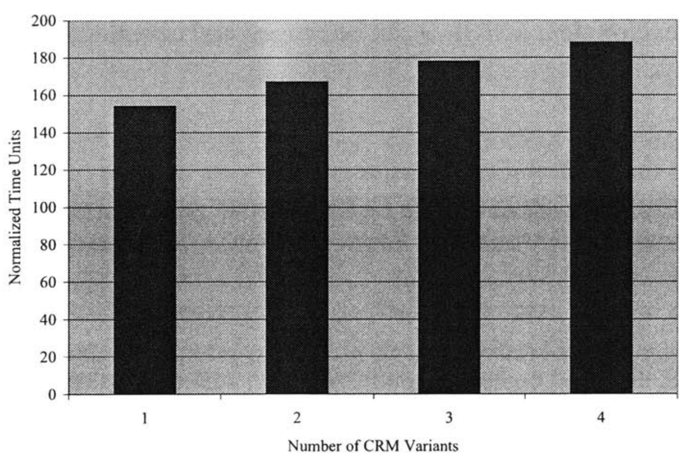

Figure 43- Product Development Lead Time vs. Number of Variants

6 CONCLUSIONS AND RECOMMENDATIONS

At higher levels assembly, the use of common parts becomes inevitable.

"To make an apple pie from scratch, you would first have to invent the universe." – Carl Seagan

TTM has been shown to be detrimental to achieving higher degrees of commonality. The drive to reduce product development lead time is not new. Understanding what the optimum TTM interval is applicable to the market being addressed is crucial. This can be done using the two methodologies previously mentioned. The first involves determining the clock speed[74] of the industry as outlined by Fine (1998), this sets the interval or industry *"tact time"*. The second involves determining where the product is in its life cycle. This can be done using the dominant design framework[75] proposed by Utterback (1996). Given these two data points one can determine the maximum appropriate development time available. This provides a planning horizon around which development activities can be scoped and commonality strategies defined.

TTC is crucial to the profitability of business. Carrying the cost of unnecessary functionality within a product is detrimental. When selecting a commonality strategy, it should be applied to the highest level of assembly which does not impact product cost. Tradeoffs between sustaining costs, carrying costs and manufacturing cost also need to be considered in determining the correct level of assembly address. For the cases studied in this paper, the ASIC

[74] Fine, Charles, 1998, "Clock Speed", Purseus Books, Reading, Massachusetts, ISBN 0-7382-0001-8, pp 3-15
[75] Utterback, James, 1996, "Mastering the Dynamics of Innovation", Harvard Business School Press, Boston, Massachusetts, ISBN 0-87584-740-4

is a good example of a part which should be common. The DTRx is a good example of a part that should not be common with respect to its implications on TTC.

One must also consider the degree of commonality to pursue. A perfectly common part is a commodity. A part shared between businesses may or may not be beneficial to all those involved. Understanding the benefits to each user is crucial in sustaining a commonality strategy. The three lens's[76] framework provides organizational insight into these types of issues. Within the Wireless BTS market for instance, Nokia has chosen to commoditize the BTS through it's sponsorship of the Open Base Station Architecture Initiative (OBSAI). L.M. Ericsson, has chosen to have a common BTS platform for both CDMA and UMTS. Finally, Nortel Networks has chosen to pursue a hybrid strategy for its BTS portfolio.

The structure of a development team has proven to be crucial in delivering commonality. Having two teams working autonomously on similar products will ultimately lead to two distinct products.

Finally, the choice of technology is crucial. Getting locked into a particular architecture, due to an underlying technology, can, be detrimental as seen in the work of Henderson[77] and Clark (1990).

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[76] Ancona, Kochan, Scully, Van Maanen and Westney, 1999, "Organizational Behavior & Processes", Massachusetts Institute of Technology, South-Western College Publishing, Boston MA, ISBN 0-538-87546-1

[77] Henderson, Rebecca and Kim Clark, 1990, "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms", Administrative Science Quarterly, 35 (1990): p 24

This paper studied the impacts of commonality on product development lead time using two methodologies. More work is required, however, in the area of grouping, linking and aligning of activities within a development project team around achieving the desired degree of commonality. Within the projects studied in this paper, commonality was championed by a single individual. The effort to align multiple disparate organizations around one commonality strategy is viewed as a barrier to the decision making process.

The DSM analysis performed in this paper is relatively simple, utilizing the higher level couplings inherent in the Nortel Networks organization and within its product development processes. Further detailed analysis, taking into account, resource constraints, individual communications between parties and unexpected iterations, would add further insight. This could ultimately provide a tool to assess the impact of a chosen commonality strategy within its current constraints.

Finally, a system dynamics view of commonality would be a useful addition to this work, in particular, with respect to understanding the difficulty in rationalizing the apparent conflict between commonality and TTM.

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APPENDICES

Appendix 1 – Task Names/Dependencies used in DTRx DSM.

Task ID	Task Name	Predecessors
1	Project Plan Approval & Funding	
2	CDMA External Interfaces Defined	1
3	UMTS External Interfaces Defined	1
4	DTRx Internal Interfaces Defined	1
5	Block1: Definition	2, 3, 4
6	Detailed Design Specification (DS) Approved	
7	Design Review CDMA	6FS
8	Design Review UMTS	6FS
9	(D) Block1 Duration	
10	JTAG Circuit schematic capture	5
11	HSSPC2 and High Speed Serial Link schemtic capture	5
12	Block2: Detailed Design	10, 11
13	Power supplies schematic capture	
14	Processor and Memory schematic capture	13FS
15	Reset Circuit schematic caputure	14FS
16	PA Control Interface schematic capture	14FS
17	Clock Circuit schematic capture	14FS, 15FS
18	Tx Channelizers schematic capture	14FS
19	Rx Channelizers schematic capture	14FS
20	(D) Block2 Duration	
21	Schematic Generation	12
22	Internal Design Review (DI)	21
23	Update Schematic 1	22
24	UMTS Stock List Generated	23
25	CDMA Stock List Generated	24

26	Specific Featured defined	25
27	Common Features defined	26
28	Block3: Verification	27
29	Functional Agreement Review (FA)	
30	Update Schematic 1	29
31	UMTS Stock List Update 1	30
32	CDMA Stock List Update 1	31
33	Specific Features Updated 1	31FS, 32FS
34	Common Features Updated 1	33
35	DFx Report Generated	30FS, 31FS, 32FS, 34FS
36	PCP Layout Generated	31FS, 32FS, 35
37	Component Placement Agreement (CPA)	33FS, 34FS, 36
38	PCP Layout Updated 1	37
39	Specific Features Updated 2	38FS
40	Common Features Updated 2	38FS, 39FS
41	Physical Agreement (PA)	29, 35, 39, 40
42	PCP Layout Updated 2	41
43	Build EC	42
44	Designer Verification Testing CDMA (DVT)	43
45	Designer Verification Testing UMTS (DVT)	43
46	WRD-024 R&D MIT (Module Integrated) UMTS	43, 45FS
47	WRD-024 R&D DIT (Design Integrated) UMTS	43, 45FS, 46FS
48	WRD-024 R&D NIT (Node Integrated) UMTS	43, 45FS, 46FS, 47FS
49	WRD-024 R&D SIT (System Integrated) UMTS	43, 45FS, 46FS, 47FS, 48FS
50	WRD-024 R&D MIT (Module Integration) CDMA	43, 44FS
51	WRD-024 R&D DIT (Design Integrated) CDMA	43, 44FS, 50FS
52	WRD-024 R&D NIT (Node Integrated) CDMA	43, 44FS, 50FS, 51FS
53	WRD-024 R&D SIT (System Integrated) CDMA	43, 44FS, 50FS, 51FS, 52FS
54	(D) Block3 Duration	
55	WRD-024 R&D PDC (Product Development Complete) UMTS	28
56	WRD-024 R&D PDC (Product Development Complete) CDMA	28
57	DTRx Design Close	55, 56
58	WRD-024 R&D CuR (Customer Ready) UMTS	55
59	WRD-024 R&D CuR (Customer Ready) CDMA	56

60	WRD-024 R&D ChR (Channel Ready) UMTS	58
61	WRD-024 R&D ChR (Channel Ready) CDMA	59

Table 11 - Coupled DTRx Development CDMA/UMTS

Task ID	Task Name	Predecessors
1	Project Plan Approval & Funding	
2	CDMA External Interfaces Defined	1
3	DTRx Internal Interfaces Defined	1
4	Block1: Definition	2, 3
5	Detailed Design Specification (DS) Approved	
6	Design Review CDMA	5FS
7	(D) Block1 Duration	
8	JTAG Circuit schematic capture	4
9	HSSPC2 and High Speed Serial Link schemtic capture	4
10	Block2: Detailed Design	8, 9
11	Power supplies schematic capture	
12	Processor and Memory schematic capture	11FS
13	Reset Circuit schematic caputure	12FS
14	PA Control Interface schematic capture	12FS
15	Clock Circuit schematic capture	12FS, 13FS
16	Tx Channelizers schematic capture	12FS
17	Rx Channelizers schematic capture	12FS
18	(D) Block2 Duration	
19	Schematic Generation	10
20	Internal Design Review (DI)	19
21	Update Schematic 1	20
22	CDMA Stock List Generated	21
23	Specific Featured defined	22
24	Common Features defined	23
25	Block3: Verification	24
26	Functional Agreement Review (FA)	

27	Update Schematic 1	26
28	CDMA Stock List Update 1	27
29	Specific Features Updated 1	28FS
30	Common Features Updated 1	29
31	DFx Report Generated	27FS, 28FS, 30FS
32	PCP Layout Generated	28FS, 29FS, 31
33	Component Placement Agreement (CPA)	29FS, 30FS, 32
34	PCP Layout Updated 1	33
35	Specific Features Updated 2	34FS
36	Common Features Updated 2	34FS, 35FS
37	Physical Agreement (PA)	26, 31, 35, 36
38	PCP Layout Updated 2	37
39	Build EC	38
40	Designer Verification Testing CDMA (DVT)	39
41	WRD-024 R&D MIT (Module Integration) CDMA	39, 40FS
42	WRD-024 R&D DIT (Design Integrated) CDMA	39, 40FS, 41FS
43	WRD-024 R&D NIT (Node Integrated) CDMA	39, 40FS, 41FS, 42FS
44	WRD-024 R&D SIT (System Integrated) CDMA	39, 40FS, 41FS, 42FS, 43FS
45	(D) Block3 Duration	
46	DTRx Design Close	25
47	WRD-024 R&D PDC (Product Development Complete) CDMA	25
48	WRD-024 R&D CuR (Customer Ready) CDMA	47
49	WRD-024 R&D ChR (Channel Ready) CDMA	48

Table 12 - Hypothetical DTRx Development CDMA Variant

Appendix 2 – Task Names/Dependencies used in CRM DSM.

Task ID	Task Name	Predecessors
1	Project Plan Approval & Funding	
2	CRM1 800 MHz M2Variant Defined	1
3	CRM2 1900 MHz M2 Variant Defined	1
4	CRM3 800 MHz RM Variant Defined	1
5	CRM4 1900 MHz RM Variant Defined	1
6	Block1: Definition	2, 3, 4, 5
7	Synthesize Specifications	
8	Partition Direct Requirements	7FS
9	Partition Indirect Requirements	8FS
10	Define External Interfaces	9FS
11	Define Internal Interfaces	10FS
12	CRM 1 Design Specification (DS) Approved	7, 8, 9, 10, 11
13	CRM 2 Design Specification (DS) Approved	7, 8, 9, 10, 11
14	CRM 3 Design Specification (DS) Approved	7, 8, 9, 10, 11
15	CRM 4 Design Specification (DS) Approved	7, 8, 9, 10, 11
16	CRM 1 Test Plan Approved	12FS
17	CRM 2 Test Plan Approved	13FS
18	CRM 3 Test Plan Approved	14FS
19	CRM 4 Test Plan Approved	15FS
20	Design Review CDMA	12, 13, 14, 15, 16, 17, 18, 19
21	(D) Block1 Duration	
22	Block2: Prototope Verification	6
23	Synthesize Digital Block & Pre D Specification	
24	Synthesize Rx Block Specification	23
25	Synthesize Tx Block Specification	24
26	Synthesize LO Block Specification	25
27	(D) Block2 Duration	
28	DVT Digital Block & Pre D	6
29	DVT Rx Block	6
30	DVT Tx Block	6

31	DVT LO Block	6
32	Block Merge	28, 29, 30, 31
33	Digital Block & Pre D Design	22, 32
34	Rx Block Design	22, 32
35	Tx Block Design	22, 32
36	LO Block Design	22, 32
37	Interface Validation	32
38	Schematic Generation	37
39	Internal Design Review (DI)	38
40	Functional Agreement Review (FA)	39
41	Component Placement Agreement (CPA)	40
42	Physical Agreement (PA)	41
43	Alpha Build EC CRM 1	42
44	Alpha Build EC CRM 2	42
45	Alpha Build EC CRM 3	42
46	Alpha Build EC CRM 4	42
47	Design Test (DT) CRM 1	43
48	Design Test (DT) CRM 2	44
49	Design Test (DT) CRM 3	45
50	Design Test (DT) CRM 4	46
51	CRM 1 Alpha Design Close	47, 48, 49, 50
52	CRM 2 Alpha Design Close	47, 48, 49, 50
53	CRM 3 Alpha Design Close	47, 48, 49, 50
54	CRM 4 Alpha Design Close	47, 48, 49, 50
55	WRD-024 MIT CRM 1	51
56	WRD-024 MIT CRM 2	52
57	WRD-024 MIT CRM 3	53
58	WRD-024 MIT CRM 4	54
59	Block3: Beta Phase Verification	55, 56, 57, 58
60	Update Schematic	
61	Functional Agreement Review (FA)	60
62	Component Placement Agreement (CPA)	61
63	Physical Agreement (PA)	62
64	Beta Build EC CRM 1	63
65	Beta Build EC CRM 2	63

66	Beta Build EC CRM 3	63
67	Beta Build EC CRM 4	63
68	Design Test (DT) CRM 1	64
69	Design Test (DT) CRM 2	65
70	Design Test (DT) CRM 3	66
71	Design Test (DT) CRM 4	67
72	Verification Report CRM 1	68FS
73	Verification Report CRM 2	69FS
74	Verification Report CRM 3	70FS
75	Verification Report CRM 4	71FS
76	CRM 1 Beta Design Close	72, 73FS, 74FS, 75FS
77	CRM 2 Beta Design Close	72FS, 73, 74FS, 75FS
78	CRM 3 Beta Design Close	72FS, 73FS, 74, 75FS
79	CRM 4 Beta Design Close	72FS, 73FS, 74FS, 75
80	WRD-024 MIT CRM 1	76FS
81	WRD-024 MIT CRM 2	77FS
82	WRD-024 MIT CRM 3	78FS
83	WRD-024 MIT CRM 4	79FS
84	(D) Block3 Duration	
85	WRD-024 R&D PDC (Prd Development Complete)	59

Table 13 - CRM Four Variant DSM Coupling (Forced Commonality)

Appendix 3 – Chronology of Nortel Networks Corporate History[78]

Early Years
1882 – Formed telephone set mfg. department of The Bell Telephone Company of Canada.
1885 – Northern Electric and Manufacturing division established
1895 – Northern Electric and Manufacturing incorporated as separate company
1913 – Northern Elec. and Western Elec. agree to reciprocal purchases and patent exchanges
1956 – U.S. government action leads to sale of AT&T shares in Northern Elec. severing access to Western Elec. patents and designs

Growth and Independence
1957 – Northern Elec. establishes R&D lab with a staff of four.
1962 – Northern Elec. becomes wholly owned subsidiary of Bell Telephone Company of
1970 – Bell-Northern Research Ltd., jointly owned by Bell Canada and Northern Elec.
1971 – Northern Elec. sets up a U.S. subsidiary – Northern Telecom Inc. – to manufacture and sell telecommunications equipment in the United States Industry Leader and Innovator
1976 – Northern Electric becomes Northern Telecom (NT) and introduces "Digital World" portfolio, the world's first complete line of fully digital telecommunications equipment
1984 – AT&T divests what become Regional Bell Operating Companies, opening the U.S. market to NT digital products that maintain a significant technological lead over the competition throughout the 1980s
1989 – NT introduces "Fiber World" initiative for systems based on fiber optic technology.

A Global Corporation
1990s – NT expands internationally, establishing alliances in Asia and Europe, and signing key contracts in Japan, China, and the United Kingdom
1992 – NT acquires Novatel Wireless and Matra Communications
1995 – NT introduces "Nortel" brand and celebrates its centenary

The Internet and New Challenges for the 21st Century
1997 – NT articulates vision of building a new Internet with the speed, capacity, reliability and security needed to underpin global communications and business
1998 – NT introduces "Nortel Networks" brand, reflecting a new focus on packet and IP-optimized network solutions.
1999 - NT name change to Nortel Networks (NN)
2000 – NN becomes fully independent when BCE Inc. reduces its holdings
2004 – NN simplifies brand to "Nortel", reflecting a new focus on simplicity, clarity and vision.

NE– Northern Electric, WE– Western Electric, NT– Northern Telecom, NN– Nortel Networks.

[78] Source: Nortel Networks corporate web site http://www.nortelnetworks.com/corporate/corptime/index.html

Appendix 4 – Effect of Commonality on Product Development Lead Time Survey

This survey is part of a paper being written on the effect of commonality on product development lead times. The objective of the paper is to establish the relationship between the use of common parts and length of time it takes to develop or change a product during the various stages of its lifecycle. Participation is completely voluntary; the information gathered will not be used for any purpose other than to support the work of this paper. No personal information will be gathered or used as part of the research.

Task Execution

The following series of questions pertain to assessing your role and your department's role in setting and executing on the commonality strategy for the product in question.

1. For this study, a common part is defined as a part that is used on higher level assemblies across multiple platforms or technologies. Using this definition what is the role of your functional organization in setting the commonality strategy for the product in question?
Scale: no role 0…..5 a significant role

2. To the best of your knowledge what other stakeholders were involved in setting the commonality strategy for the product in question?

3. What were the roles of the other stakeholders in establishing the commonality strategy – why were they involved?

4. Once the commonality strategy had been established how was the work structured/organized in order to maintain commonality?
Scale: ad hoc 0…..5 very structured around commonality goals

5. How was commonality linked to the top level metrics of the product namely quality, cost and time to market?
Scale: no linkage 0…..5 tight linkage (commonality was a top level metric)

6. Which Life Cycle Management phases were more work, which were less work for you with respect to a no commonality strategy having been chosen?
Scale: less work 0, same amount of work 3 and more work 5

7. Specifically with respect to organizational structure how was your work impacted by the commonality strategy chosen? For instance, were multiple sites involved? Were other groups with the same functional mandate involved? Was it necessary to communicate across multiple time zones? Did the number of meetings increase? Was language an issue?
Scale: low to no impact to work due to organizational structure 0…..5 high impact to work due to organizational structure.

Decision Making

The following series of questions pertain to how the commonality of the product in question fits in with the short and long term business objectives of the organizations in which it was or could have been deployed.

1. Within your role are you accountable for meeting the business objectives of any particular line of business? Did these objectives influence your decision on the degree of commonality to pursue with respect to the product in question?
Scale: low degree of influence 0.....5 high degree of influence

2. To the best of your knowledge, how well did the commonality strategy chosen align with the specific business objectives of the other stakeholders?
Scale: poor alignment 0.....5 excellent alignment

3. What, if any, constraints were placed on the commonality strategy by the stakeholders in order to ensure that their own interests were not compromised?
Scale: no constraints 0.....5 a great number of constraints

4. Once the commonality strategy had been established, how were tradeoffs performed in order to ensure equity between all shareholders?
Scale: no consideration of equity 0.....5 high consideration for equity between stakeholders.

5. Which of the following top level product metrics namely quality, cost and time to market conflicted most with the commonality strategy chosen? Between which stakeholders did the biggest differences in interests/objectives exist? Who had the most to loose by not meeting their objectives?

6. Did the commonality strategy originally set change at any time during the Life Cycle Management process? If so, at what phase did it change, what stakeholders where involved and what rationale was given?
Scale: no change 0.....5 complete abandonment

7. Did you feel that the interest of your functional department, business or Nortel Networks as a whole was best served by the commonality strategy chosen? Please describe any compromises that you felt were made on behalf of your function or those you represent.
Scale: contradicts departmental interests 0, 3 neutral, 5 furthered interests of department

8. Did a transfer of design control/authority occur from one group to another because of the commonality strategy chosen?
Scale: no transfer of design control 0, shared control 3, full transfer of design control 5

Culture

In every organization there is a unique culture. For instance the culture in Nortel Networks prior to the right angle turn in 1997 was quite different than the culture today. The following series of questions pertain to how the culture within Nortel Networks impacted the commonality strategy of the part in question.

1. Briefly describe Nortel Networks culture and some of its main attributes during the development of the part in question?

2. Of each of the stakeholders involved are there any sub cultures which exists between groups, sites, lines of business or functions. If so, please describe them.

3. Briefly which attributes of Nortel Networks culture do you believe enhance a commonality strategy and which do you believe deter from it.

4. Do you believe that a higher degree of commonality between platforms in the Wireless business would be of benefit to Nortel Networks? Why/Why Not?
Scale: no benefit 0……5 very beneficial