DEPARTMENT OF INDUSTRIAL ENGINEERING

UNIVERSITY OF STELLENBOSCH

THE APPLICATION OF NECESSARY BUT NOT SUFFICIENT PRINCIPLES TO THE IMPLEMENTATION OF PRODUCT LIFECYCLE MANAGEMENT SOFTWARE

by

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Engineering (Industrial) at the Faculty of Engineering Stellenbosch University

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MARCH 2007

Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.

Ek, die ondergetekende verklaar hiermee dat die werk gedoen in hierdie tesis my eie oorspronklike werk is wat nog nie voorheen gedeeltelik of volledig by enige universiteit vir 'n graad aangebied is nie.

Signature: **Date:**

SYNOPSIS

Product Lifecycle Management (PLM) is defined as the business activity of managing a company's products across the product lifecycle.

Product Data Management (PDM) systems are the primary system component of PLM. The focus of this research is on the implementation of PDM software within the context of PLM.

Fifty percent of all PLM projects fail. Failure implies no bottom-line benefit is achieved with the implementation. The main reason for failure is not the technology but the implementation approach used.

The research question addressed by this thesis is: How can it be ensured that bottom-line benefit is achieved with the implementation of PLM technology?

The Necessary but not Sufficient (N&S) solution is based on Theory of Constraints principles and was developed to help achieve significant bottom-line benefit with the implementation of new technology. This is accomplished through focusing on the removal of limitations (something that prevents the company from better achievement of its goal of increasing profit) as well as addressing the necessary organisational changes (the N&S solution refers to the changing of customs, habits, policies, procedures, metrics and behaviour).

This research applies the N&S solution to the PLM software environment in order to address the research question.

The outcome of the project is an implementation methodology that will ensure bottom-line benefit will be achieved with the implementation of PLM software.

This implementation methodology was applied to a practical case study from an analysis point of view and was validated with cause and effect logic.

OPSOMMING

Produk Lewensiklus Bestuur behels die effektiewe bestuur van 'n maatskappy se produkte oor die produk se lewensilus.

Produk Data Bestuur (PDM) sagteware stelsels is die primêre stelselkomponent wat gebruik word in Produk Lewensiklus Bestuur. Die realiteit is dat vyf uit tien PDM sagtware implementerings projekte onsuksesvol is. 'n Onsuksesvolle projek impliseer dat geen waarde toegevoeg is tot die maatksppy se welvarendheid nie. Die hoofrede wat toegeskryf word daaraan is dat die verkeerde benadering gebruik word vir die implementering van die tipe sagtware.

Die navorsingsprojek beantwoord die volgende vraag: Watter benadering moet gebruik word met die implementering van PDB sagteware om te verskeker dat die maatskappy meer winsgewend is?

Die 'Necessary but not Sufficient (N&S)' oplossing is gebasseer op 'Theory of constraints' beginsels. Dit is ontwikkel en toegepas op die implementering van ERP sagteware stelsels met die doel om winsgewendheid met die implementering van die sagtware te verseker.

Die N&S oplossing fokus op die volgende twee aspekte:

– Die verwydering van elemente wat die maatksappy hinder om te slaag in hul doel van winsgewendheid.
– Die identifikasie van besigheidsreëls wat verander moet word saam met die implementering van die nuwe sagteware. Die verandering in besigheidsreëls sluit paradigmaskuiwe in.

In die navorsingsprojek word die N&S oplossing toegepas op die implementering van PDM sagtware. Die toepassing word gebruik as basis vir die ontwikkeling van 'n metodologie wat gebruik moet word vir die implementering van PDM sagtware. Die doel van die metodologie is om 'n toename in winsgewendheid vir maatskappye te verseker met die implementering van PDM sagteware.

Acknowledgements

Special thanks to Mr. Konrad Bartel: Thank you for your hard work, mentorship, enthusiasm and compassion.

Thank you to Prof. Dimi Dimitrov for valuable insights, guidance and for supporting the research project.

Thanks to my family and loved ones for their love and constant encouragement.

Thank you to the following companies and institutions for enabling this research and for their respective contributions:

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GLOSSARY

Acronyms

BM	Buffer Management
BOM	Bill Of Materials
CAD	Computer Aided Design
CCPM	Critical Chain Project Management
CE	Concurrent Engineering
CM	Configuration Management
CRT	Current Reality Tree
DAS	Denel Aerospace Systems
DDP	Due Date Performance
ECP	Engineering Change Proposal
ERP	Enterprise Resource Planning
FRT	Future Reality Tree
I	Investment
IRD	Inventory Rand Days
ISC	Information Supply Chain
IT	Information Technology
MRP	Material Requirements Planning
N&S solution	Necessary but not Sufficient solution
NP	Net Profit
OE	Operating expense
PDM	Product Data Management
PLM	Product Lifecycle Management
QOTIF	Quality On Time In Full
ROI	Return On Investment
T	Throughput
TOC	Theory Of Constraints
TRD	Throughput Rand Days
UDEs	**U**n**D**esirable **E**ffect**s**
WIP	Work in Process

Definitions

Benefit	Benefit is achieved when a change causes a better achievement of the system's goal.
Current Reality Tree	A cause and effect diagram that depicts the current reality of a system

Full benefit	An improvement process is sufficient when nothing else can be done to achieve a better realisation of the system's goal; therefore full benefit has been achieved from the improvement effort.
Future Reality Tree	A cause and effect diagram that depicts the future reality of a system
Inventory Rand Days	IRD measures the effectiveness of a distribution system. It is calculated by multiplying the Rand value of the inventory at hand by the time the inventory entered the responsibility of the link
Investment	Investment is the money that the system has invested in purchasing things it intends to sell.
Limitation	A limitation is anything that prevents a system from achieving higher performance towards its goal.
Necessity	Something (an activity/ a change/ new technology) that brings benefit by diminishing a limitation.
OE	The money that the system spends to turn inventory into throughput
Rules	Collectively known as customs, habits, policies, metrics and behaviour
Sufficiency	An improvement process is sufficient when everything (all activities/aspects within the boundaries of the system), that brings benefit by diminishing a limitation, has been exploited. Therefore an improvement process is sufficient when all the necessities have been exploited.
Throughput	Throughput is defined as the rate at which money is generated by the system through sales
Throughput Rand Days	A measure of reliability that is determined by multiplying the Rand value associated with not meeting a commitment with the time that the commitment is late
Undesirable effects	Undesirable effects are symptoms or negative effects experienced in current reality. These effects are undesirable because they inhibit the better achievement of the goal of the system.

Chapter 1:

INTRODUCTION

1.1 BACKGROUND

One of the latest software technologies available to the business world is Product Lifecycle Management (PLM). PLM emerged in 2001 (Figure 1.1) and is defined as "the business activity of managing a company's products all the way across the lifecycle in the most effective way" (Stark, 2005b).

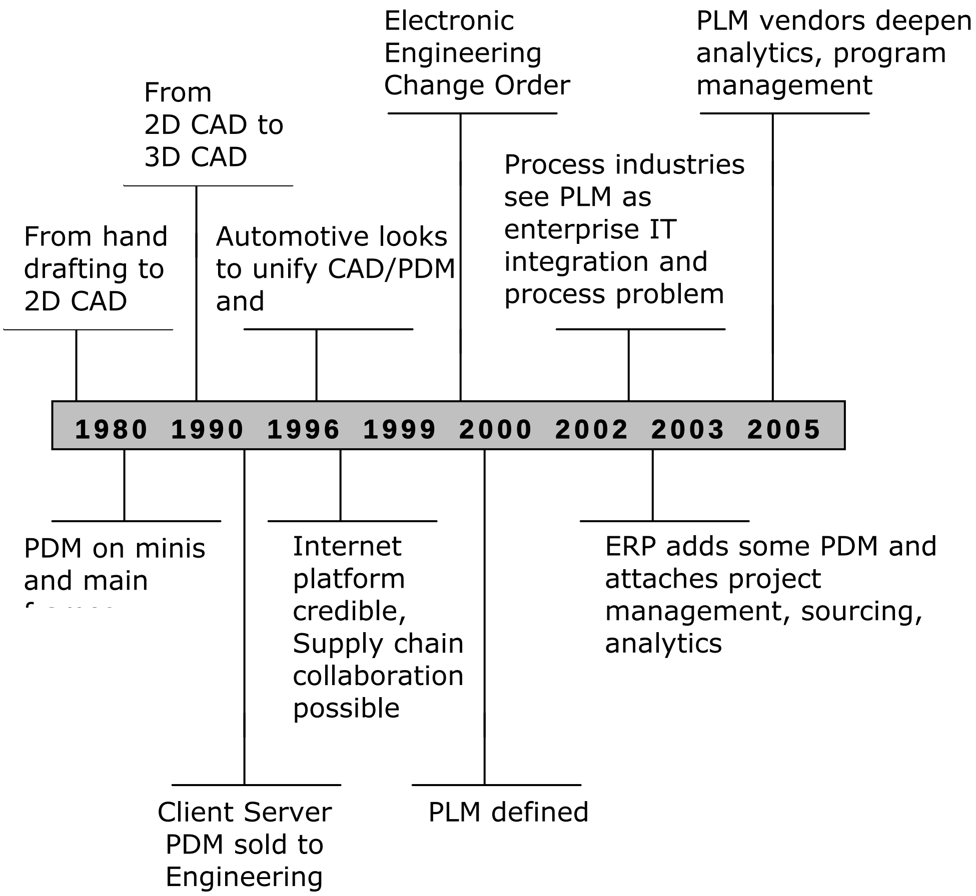

Figure 1.1: PLM timeline

(Burkett *et al.*, 2003)

The concept of Product Lifecycle Management was founded due to several internal and external drivers. The internal drivers include the need for product innovation, customer intimacy and operations excellence. On the other hand globalization, mass customization, product complexity, the contraction of product life cycles, the push into the supply chain and environmental issues altogether formed the external forces (Ameri and Dutta, 2004).

The following comment from Downes (2002) establishes the importance of the PLM approach to product data in the future:

> "The complete flow of information about each product over its lifetime will develop into a parallel supply chain: an information supply chain (ISC) that describes its physical counterpart in precise detail. Given the potential value of this staggering amount of data, the ISC will be the source not only of a company's leverage within its industry, but of future products, services, and profitability. A company's survival will increasingly depend on how it manages the information in this supply chain".

PLM is a holistic approach, addressing multiple components such as applications, processes, people and data. It addresses the product across the lifecycle, from "cradle to grave", across the extended enterprise.

The scope and complexity of PLM software is comparable to CAD and ERP (Stark, 2005a:407). Stark states that many implementations of enterprise-wide information system solutions fail; surveys claim that failure rates are as high as 50% (2005a:60). In this context, failure implies that the implementation of the technology did not result in any bottom-line benefit: "The main reason for failure is not the technology but the implementation approach" (Stark, 2005a:405).

As a result of the reality facing PDM implementations, the need was recognized for the development of a new implementation approach. The approach must address the common reasons for failure and ensure bottom-line benefit - the ultimate measure of implementation success - is achieved.

Goldratt acknowledged the increase in failed ERP implementations. Consequently he developed the Necessary but not Sufficient (N&S) solution to help ensure value is added with ERP implementations. This is accomplished by focusing on the removal of limitations (factors that prevent the company from better achievement of its goal). In addition to this, the necessary organisational changes that must take place with the implementation of the software must be addressed. The N&S solution refers to the organisational changes as the changing of rules. These rules include paradigms, customs, habits, policies, metrics and behaviours.

1.2 PROBLEM STATEMENT

Product Data Management (PDM) systems are the primary system component of PLM. The focus of this research is on the implementation of PDM software within the PLM environment.

The research question for this thesis is: What implementation approach must be used in order to ensure that value is added with the implementation of the PDM software component of PLM technology?

This research applies the N&S solution in order to address the research question because the N&S solution was developed specifically to address the failure of ERP enterprise-wide software solutions. In addition it is the only approach that proposes implementation of a holistic management paradigm with the roll-out of the software. PLM is supported by such a paradigm.

Therefore, the aim of the project will be to develop a PDM software implementation methodology based on the N&S solution. The methodology will be presented on a generic level; specific implementations will necessitate the addition of more detailed tasks.

In particular the objectives of the research are the following:

- Apply the N&S solution to the PDM software environment
- Develop a PDM software implementation methodology
- Analyse the case study according to the developed implementation methodology
- Use TOC analysis tools to validate the implementation methodology. By doing so a further case study will not be necessary.
- Make recommendations to the case study implementation based on the findings from the analysis and validation.

The key attributes of the methodology must address the common reasons for PLM implementation failure and ultimately ensure a successful implementation. The methodology must provide assistance in:

- Determining the necessity of the PDM software.
- Determining the ROI for the implementation.
- Achieving top management buy-in and support for the implementation project.
- Determining the extent of organisational change that is necessary with the implementation of the new PDM software.
- Developing a roadmap for implementation success.
- Developing an implementation plan that will achieve an increase in company profit.

1.3 RESEARCH APPROACH

The research project was structured as follows:

1. Literature Study

2. Application of the N&S principles to the PDM software environment

3. Development of a generic implementation methodology based on the findings in step 1 and step 2:
   - A structured approach or methodology is a set of steps to be followed to solve a problem (Bernus *et al*., 1996:10).
   - The methodology was developed as a generic roadmap for the implementation of PDM and, ultimately, PLM software. It is a tool that can be used alongside the technical implementation of the software. The technical implementation refers to steps such as data migration, the definition of certain specifications in order to set up the software, customization of the software and the roll-out strategy.
   - The methodology portrays the following:
     - Specific steps that should be completed with the implementation
     - The tools that should be used to complete each step
     - Guidelines are given for the application of each step of the methodology.

4. Analysis of a PDM software implementation according to the developed implementation methodology (i.e. the application of the implementation methodology to the PDM software environment from an analysis point of view):
   - The analysis was done on the implementation of PDMLink software in the Engineering Services department of Denel Aerospace Systems (DAS). This department is mainly responsible for configuration management and creating engineering drawings.
   - The PDM software implementation was done according to a process/approach defined by the implementer, Automated Reasoning.
   - Undesirable effects were identified and used in the analysis.
   - The findings of the analysis were used to refine the implementation methodology.

5. Implementation methodology validation:
   - The implementation methodology was validated through cause-and-effect analysis. TOC analysis tools were used. TOC is a systematic approach and it provides a set of powerful tools that can be used to analyze systems (Pfeifer *et al*. 2007).

6. Recommendations:
The research was done as an external project to a case study implementation (Figure 1.2). The observations and analysis of the case study lead to the refinement of the developed implementation methodology.

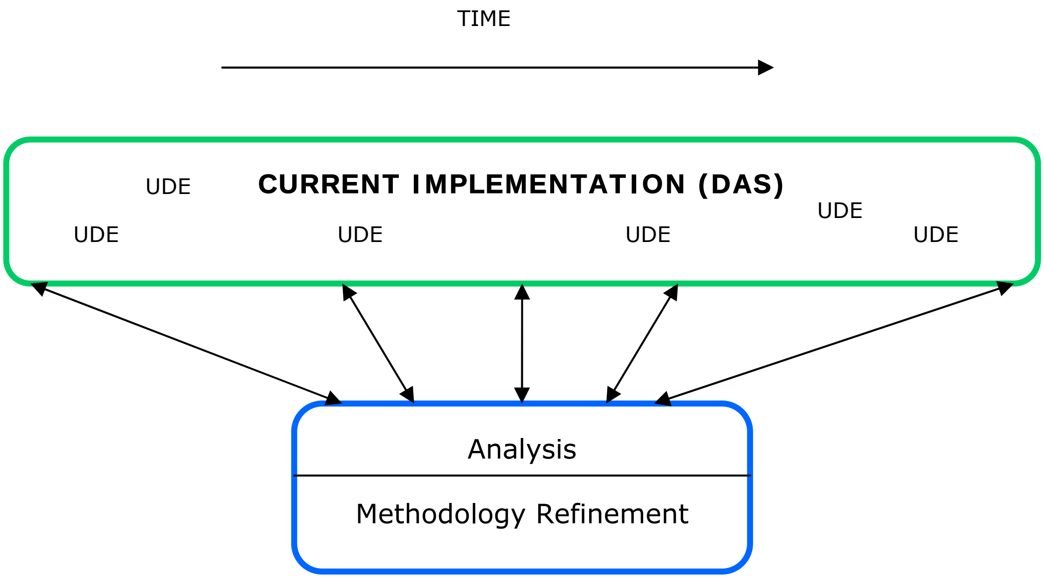

Figure 1.2: The research approach

1.4 RESEARCH OUTLINE

Chapter 2 introduces product lifecycle management and the related PDM software.

Chapter 3 starts with a brief overview of study fields related to PLM. Thereafter a research review is given of current implementation methodologies, approaches and methods for the enterprise-wide information systems of ERP, PLM and PDM.

A Theory Of Constraints (TOC) solution, the N&S Solution, was developed to help ensure the achievement of bottom-line benefit with the implementation of technology. Chapter 4 introduces some key TOC concepts. Chapter 5 introduces the N&S solution.

Chapter 6 is dedicated to the application of the N&S solution to the PDM software environment.

The findings from the application of the N&S solution to PDM were used as a basis to develop a PDM software implementation methodology for the achievement of bottom-line value. The generic implementation methodology is presented in Chapter 7.

The Product Data Management Software Implementation Methodology was applied to a practical implementation for the purpose of analysis. The process and logic followed is described in Chapter 8.

Chapter 9 discusses the current reality of the practical implementation. The implementation methodology is validated using cause and effect logic. Lastly recommendations are made for the improvement of the current implementation approach.

Chapter 10 provides a summary of the research and findings, as well as conclusions and recommendations.

The flow diagram below (Figure 1.3) illustrates the structure of the thesis.

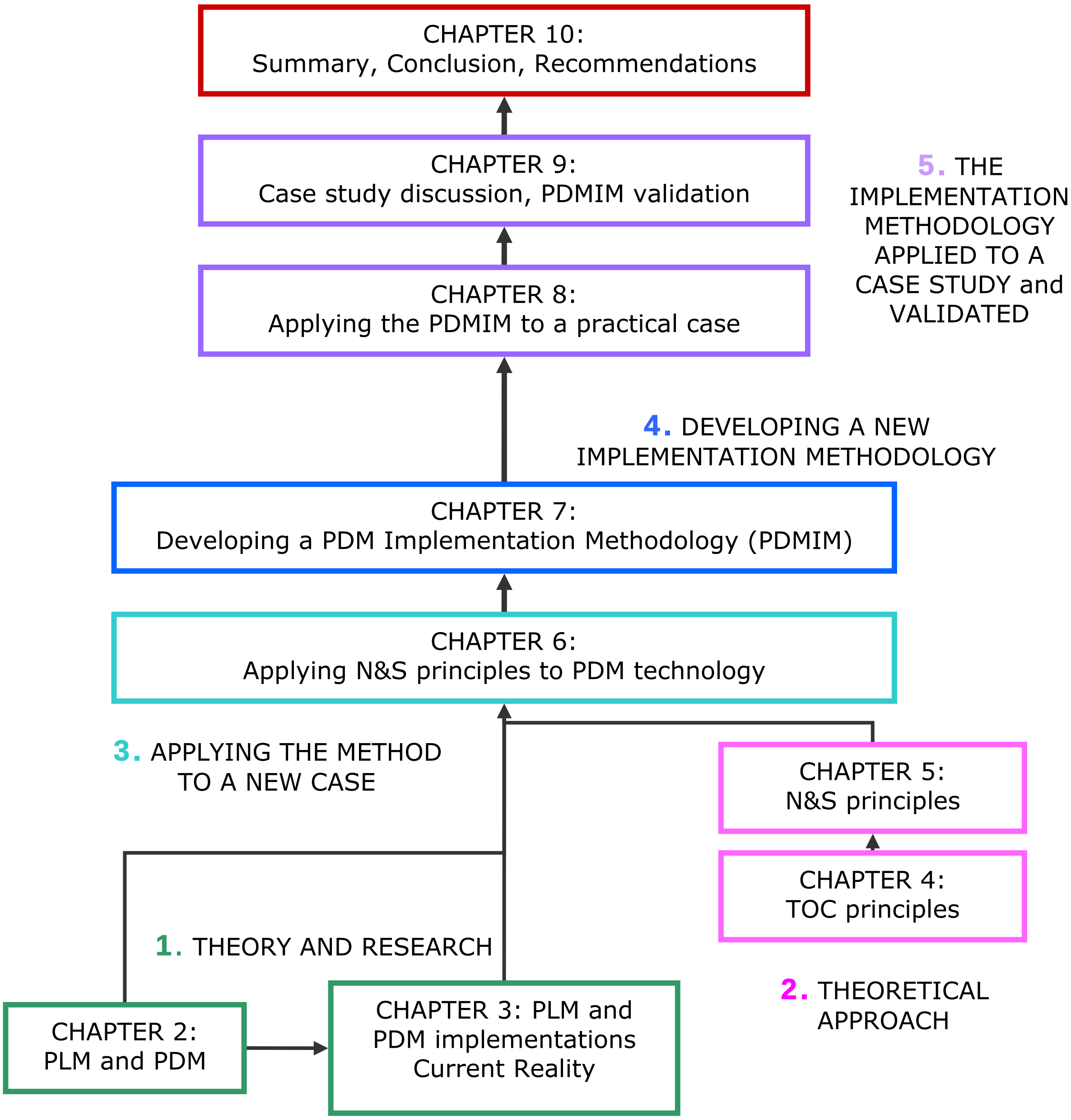

Figure 1.3: Schematic flow of Chapters

Chapter 2:

PRODUCT LIFECYCLE MANAGEMENT AND APPLICATIONS

2.1 DEFINING PLM

A product lifecycle typically consists of the following phases (Figure 2.1): Business idea, Requirements Management, Development, Production, Operation, Maintenance, and Disposal (Asklund *et al*., 2003:5-6).

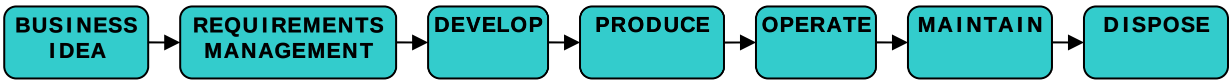

Figure 2.1: A product lifecycle

The business idea phase begins with a perception of a new product, and then the requirements are defined. Thereafter the development of the product starts. A generic development process contains six steps (Ulrich and Eppinger, 1995:13):

- The detailed requirements phase.
- Conceptual development in which the product concepts are generated.
- At the system-level design, the architecture of the product, including the identification of subsystems and components, is decided.
- The components are further designed during the detailed design phase.
- Testing and refinement include the building of prototypes to test both the product and production systems.
- During the production ramp-up the industrialization of the product takes place.

After development the product is produced and then delivered to customers. To ensure correct operation, the product may require continuous support and maintenance. The final phase of the life cycle of a product is its disposal, during which the environment must be taken into consideration.

PLM constitutes the management of a company's products throughout the product lifecycle.

Other formal definitions include:

- A business strategy that helps companies share product data, applies common processes, and leverages corporate knowledge for the development of products from conception to retirement, across the extended enterprise (Salustri, 2005).

- CIMData defines Product Lifecycle Management as a strategic business approach that applies a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise from concept to end of life, integrating people, processes, business systems, and information (Garetti, *et al*., 2005:44).

With PLM the focus moves to the product and a holistic approach to the product lifecycle and its activities. PLM integrates many processes, disciplines, functions and applications that have previously been seen as separate and independent. All of these would address the same product, but every one would utilise its own vocabulary, rules, culture and language (Stark, 2005b). PLM extends and brings together Computer Aided Design (CAD), Product Data Management, Configuration Management, Group Technology, Sustainable Development, Product Portfolio Management and Recycling, amongst others.

PLM business processes provide the context in which product data is created (product development processes etc.), used (production-, supplier management -related processes, etc.), maintained and changed (change management, issue management processes, etc.) and archived (product liability management, production ramping down related processes, etc.) (Huijben, 2005a).

PLM has a broad scope. It encompasses Portfolio Management, Program Management, Collaborative Design, Product Data Management, Manufacturing Process Management, and Service and Support Management (Figure 2.2). Combined, these solutions enable a company to manage products over their entire lifecycles. PLM provides a common framework that supports the visibility of data and processes across these applications.

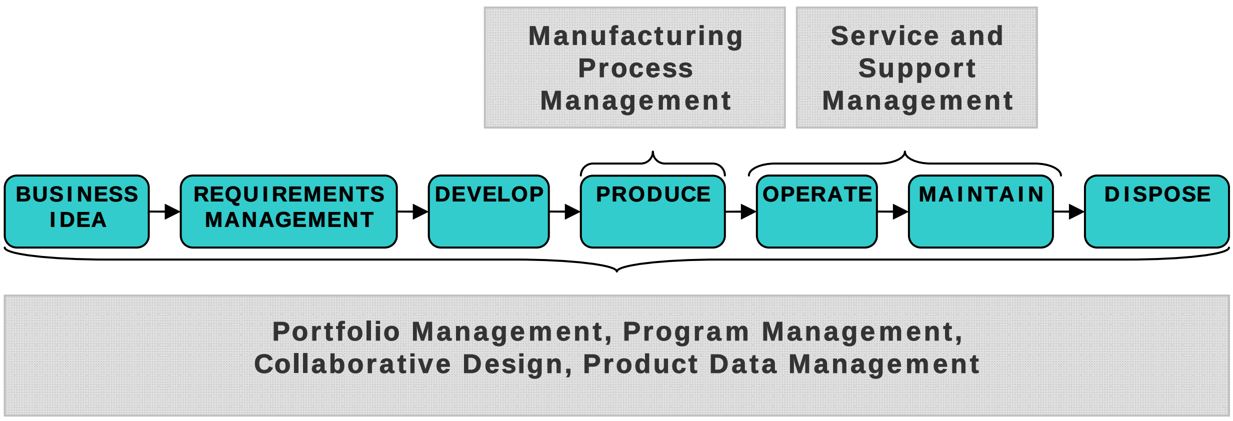

Figure 2.2: PLM supports product lifecycle solutions

The holistic PLM approach is supported by:

- A horizontal, lifecycle-oriented company: distinctions are made between product lines i.e. knowledge workers from different functions work together in teams and each team focuses on a specific product line(s).
- Integrated or concurrent product development that involves collaboration throughout the extended enterprise.
- A holistic approach to the management of the product lifecycle and its activities.
- Standard processes, data and systems throughout the extended enterprise.

The objective of PLM is to improve company revenues and income by maximizing the value of the product portfolio (Stark, 2005b).

Revenues can be increased by either increasing price and/or increasing the volume of products sold. Being first in the market; offering innovative products; offering improved and a wider range of products and services can increase the volume of products sold. With exceptional performance price premiums can be charged. These abilities can be achieved with improvements such as reduced development time and increased product and service quality claimed as possible improvements with the implementation of PLM.

Possible improvements that can be achieved with the use of PLM include (Stark, 2005a:2):

- Reduce product development costs by 15 %
- Reduce product development time by 25 %
- Reduce engineering change time by 30%
- Reduce number of engineering changes by 40%
- Less obsolete inventory
- Less safety stock
- Improvement in design and process reuse
- Time to market decreased
- Product cost decreased
- Warranty cost decreased
- Productivity increased
- Efficiency increased
- Quality increased; scrap and rework cost decreased
- ECN cycle time decreased up to 50%
- Cost per ECN decreased

2.2 PLM APPLICATIONS

In the past, application systems could only manage products to some extent, across some part, or parts, of the lifecycle. Product lifecycle management breaks down the technology silos that have limited interaction between those who design products and those who build, sell, and use the product (Bertoline *et al.*, 2005).

A PLM system may not necessarily be one physical, or even one logical, system. It is an IT architecture owning all product-related information (Huijben, 2005b).

PLM functionality consists of different elements (Stark, 2005a:407):

- Product data management and configuration management (the primary system component)
- Product and process definition
- Collaboration software
- Visualization/ Viewing
- Data exchange
- Customer-oriented and Supplier oriented applications
- Definition and management of product lifecycle processes
- Project management
- Portfolio management
- Integration (Integration between PLM components as well as integration between the PLM software and other systems such as Customer Relationship Management systems, ERP or Supply Chain Management software)

Parallel with the continued development of Computer–Aided Design and Manufacturing and Engineering (CAD/CAM/CAE) tools, Product Data Management (PDM) systems appeared during the 1980s to control and manage product information created by the information authoring tools. The need for easy, quick and secure access to valid data was the major driver behind the development of PDM as a more disciplined and dedicated data control solution. Current PDM systems include functionalities such as change management, document management, workflow management and project management.

Basic components of a PDM system (Figure 2.3) include (Stark, 2005a: p.233):

- The information vault or repository
- The information management module that manages the information vault; it is responsible for such issues as data access, storage, and recall, information security and integrity, concurrent use of data, and archival and recovery. It provides traceability of all actions taken on product data.

- The user interface
- System interfaces for programs such as CAD and ERP
- Information and workflow structure definition functions which are used to define the structure of the data and workflows to be managed by the PDM system.
- Information structure management functions that maintain the exact structure of all information in the system across the product lifecycle.
- Workflow management functions that keep workflow under control, for example, managing engineering changes and revisions
- System administration functionality which is used to set up and maintain the configuration of the system and to assign and modify access rights.

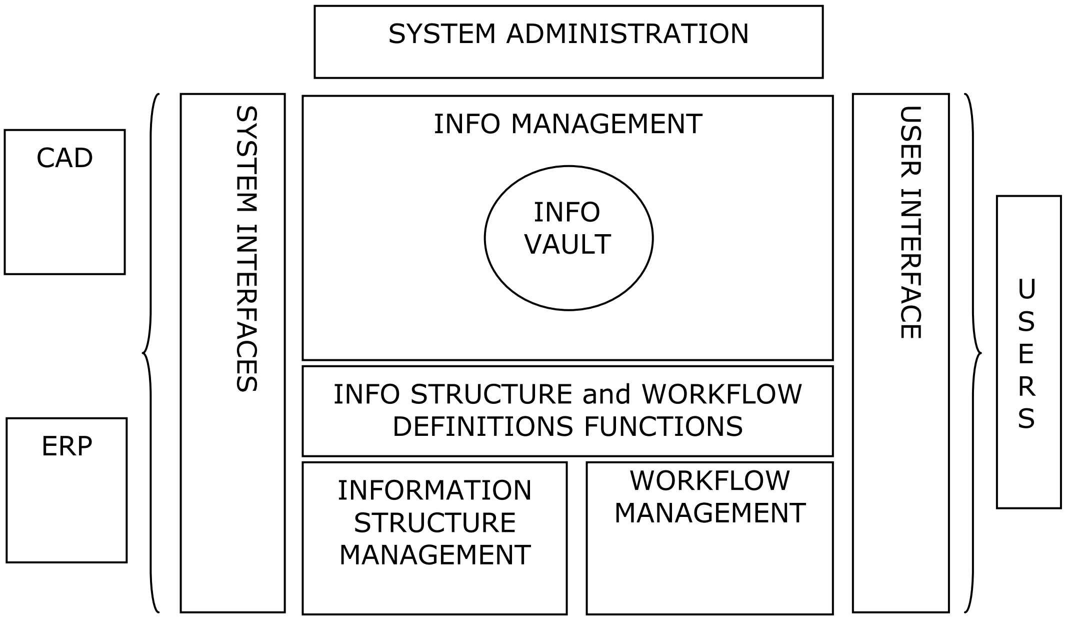

Figure 2.3: The building blocks of a PDM software system

PDM is product centred (as opposed to traditional document and electronic document management systems that have a document or image centred focus). It includes robust configuration management capabilities and makes use of workflow technology to support the automation of product data processes, such as release processes and the engineering change process.

The main task of configuration management (CM) is to ensure that there is a correct set of documentation for each version of a product. Guess defines CM as the process of managing organisations, products, facilities and processes by managing their requirements, including changes, and assuring that the results conform in each case (2002:21).

The activities of configuration management include: requirements management, change management, release management, data management, records management, document control and library management.

Requirements management involves managing the conformance to product requirements throughout the product lifecycle. Change management is the process that manages the engineering change process. Release management manages the rules and checks that allow documents or forms to be released. Data management manages the movement of the evolving product data. Records management serves to provide evidence that specific work was performed and the desired result was achieved. Document control involves creating, recording, reviewing, controlling, obtaining approval for, releasing and changing controlled documents. Library management includes managing the sharing of available product data resources.

All these activities include interaction between different people/team members involved in the product lifecycle. The workflow functionality enables that documents are automatically tracked to team members, team members are automatically notified of the next task to be done, files are routed and distributed, and approvals are recorded electronically. The workflow system is basically a rules-based system that controls access to documents and data and supports the electronic execution of configuration management activities.

A PDM system basically consists of two functionalities:

1. A product information system
2. Automated product data configuration management processes that is enabled by the workflow functionality incorporated in the system.

Benefits from implementing PDM in the context of PLM range from significantly improving the product data information management and improving the control of certain product data processes through to major benefits. Major benefits include reducing product development times by 25%, reducing engineering cost by 15% and improving product quality (Stark, 2005a:321).

Chapter 3:

CURRENT PLM IMPLEMENTATION APPROACHES

In the first section of this chapter a few study fields related to PLM are briefly introduced.

Although the concept of PLM has existed since 2001, a study of the academic and trade literature over the past two years have yielded limited systematic investigation of PDM implementation methodologies or practices.

PLM is similar to ERP, in that it falls into the enterprise-wide software solution category. ERP is a widely implemented application and its implementation methodologies have been developed and refined over several years. Thus this research review starts with a brief discussion of ERP implementation methodologies and approaches. In addition to this, those factors that have been identified as being critical in the successful implementation of ERP will be discussed.

Following this discussion, three specific commercial PLM software packages and their implementation approaches will be introduced. The chapter concludes with an assessment of a number of general PLM implementation approaches and methods.

3.1 PLM RELATED STUDY FIELDS

The following study fields are related to PLM and PDM:

- Business Process Reengineering
- Concurrent Engineering
- Systems Engineering
- Change Management

3.1.1 Business Process Reengineering (BPR)

BPR is defined as: the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical contemporary measures of performance, such as cost, quality, and speed (Chase, *et al*.,2001: 655).

This definition of BPR shows the focus in cost reduction.

3.1.2 Concurrent Engineering:

Concurrent Engineering is defined as a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from outset, to consider all elements of the product life cycle from conception to disposal, including quality, cost, schedule, and user requirements (Singh, 1996:103).

Some common problems that still represent barriers to CE are (Turino, 1992:27):

- Organisational considerations:
  The traditional functional organisation of a company is characterised by separation rather than integration of the various functions and disciplines in the organisation. This promotes separatism, empire building and barriers to communication. The concurrent engineering organisation, on the other hand, has contributors from each discipline reporting to a product (or project) team leader.

- Accounting considerations:
  The traditional accounting systems in most companies are an impediment to the CE process. Each department's cost data is measured individually and reported without regarding the impact of investments in the company's performance as a whole. If the design engineers exceed the budget by a small percentage, in order to ensure that all components can be built, tested and serviced at significant savings, they tend to be penalised instead of being rewarded (Turino, 1992:29).

The CALS/CE Electronic Task Group identified the following four major elements of the concurrent engineering environment (Singh, 1996:19):

- Organisation
- Requirements
- Communications
- Product development methodology

The CALS/CE Electronic Task Group developed a matrix in which the various levels of each element and its respective sub-elements are summarized. The matrix can be used to assess the current CE climate in an organisation and to identify areas requiring improvement. All the elements must support a CE methodology for it to succeed. Existing policies often counteract the intentions of CE. The matrix focuses attention on several specific categories of the elements in order to help identify new policies that are crucial to successful adoption of CE methods.

The sub elements are given in Table 3.1:

MAJOR ELEMENT	**ORGANISATION**	**REQUIREMENTS**	**COMMUNICATION**	**PRODUCT DEVELOPMENT METHODOLOGY**
SUB ELEMENT	Team membership	Product definition	Management of working data	Optimization
	Team leadership	Schedule types	Data acquisition and sharing	Data libraries
	Team member contribution	Planning style	Lessons learned feedback	Development process
	Business interrelationships	Validation of specifications to requirements	Decisions traceability	Reviews
	Training and education		Interpersonal	Process measurements
	Responsibility and authority			Analysis architecture
	Management decisions			Verification

Table 3.1: CE elements

3.1.3 Systems Engineering

Systems engineering is a critical new frontier for PLM strategy (Burkett, et al., 2003: 9).

A simple definition of systems engineering is: It guides the engineering of complex systems (Sweet *et al*., 2002: 3).

A system is defined as a set of interrelated components working together toward some common objective (Sweet *et al*., 2002: 3).

Systems engineering is focused on the system as a whole – it emphasizes its total operations (Sweet *et al*., 2002: 4).

3.1.4 Change management

Change management acknowledges the phenomenon of resistance to change. It focuses on the management of people in a changing environment, in order to ensure that business changes are successful and that the desired business results are realised. Several principles, methods and techniques exist to support change management initiatives.

3.2 ENTERPRISE-WIDE INFORMATION SYSTEM SOLUTIONS

"A methodology is a roadmap to an implementation" (Bruges, 2000:1).

The main phases of three ERP methodologies are presented (Burges, 2000:1-4) in Table 3.2. All the methodologies address the following:

- Defining the goal, scope and objectives of the implementation project
- Ensuring top management buy-in
- A business process reengineering component in which new business processes, policies, procedures, and performance measurements are defined
- Change management
- System configuration and installation
- Training
- Monitoring and measuring implementation against defined objectives

PHASES	AcceleratedSAP (ASAP) Vendor specific methodology	The Total Solution (Ernest and Young) Consulting firm product	The Fast Track Work plan (Deloitte and Touche) Consulting firm product
1	Project Preparation	The Value Proposition: Building the business case	Scoping and Planning: Project planning is initiated;
2	Business Blueprint	Reality Check: Assessing an organisation's readiness for change	Visioning and Targeting: Vision and targets are identified;
3	Realisation	Aligned Approach: Setting expectations	Redesign: Software design and development are started;
4	Final Preparation	Success Dimension	Configuration: Integration is planned.
5	Go live and support continuous change	Delivering Value: Measuring results and celebrating success	Testing and Delivery: System is delivered.

Table 3.1: ERP methodologies

A contingency framework for ERP implementation approaches (Brown *et al.*, 1999:412) suggests that the organisational characteristics and desired ERP package capabilities influences the ERP package choice and project scope. This, in turn, influences key ERP implementation choices. The key choices represent the identified critical success factors for an ERP implementation. The critical success factors are:

- Top management support
- Composition and leadership of the project team
- Attention to change management
- Usage of 3rd party consultants
- Manage complexity by:
    - Extent of process innovation
    - Degree of package customization
    - Conversion strategy (phased, big-bang or pilot)

3.3 COMMERCIAL PLM SOFTWARE SOLUTIONS

PLM suite technology providers all deliver some level of functionality across the PLM footprint. The vendors approach the PLM problem from different directions based upon their historical strength in the data and processes that they have managed (Burkett, et al., 2003: 3-4). Vendors can be categorized as follows:

- CAD application vendors - they offer PDM capabilities that best use these applications and the digital model.
- Independent PDM vendors - they offer PLM processes as a neutral application regardless of legacy systems.
- ERP vendors offer PLM as an additional module which uses business information and includes supplier- and customer-facing capabilities.
- Services - these vendors come from a history of building and deploying complex systems. While either owning or closely partnering with a PLM software provider, their services are a core competence.

A review of available PLM solutions and implementation approaches are given: The available PLM solutions of PTC (CAD application vendors), MatrixOne (independent PDM vendor) and SAP (ERP vendors) as well as their respective implementation approaches and/or support will now be presented.

PTC's PLM solution is in the form of a product development software suite that supports the activities of creating products and product information. It enables collaboration between the different entities involved in the product lifecycle. Furthermore, it supports the activity of controlling product information and product development processes throughout the product's lifecycle.

Figure 3.1 portrays the software solutions that support each of the three main solution components, as well as the fundamental process components supported by the system.

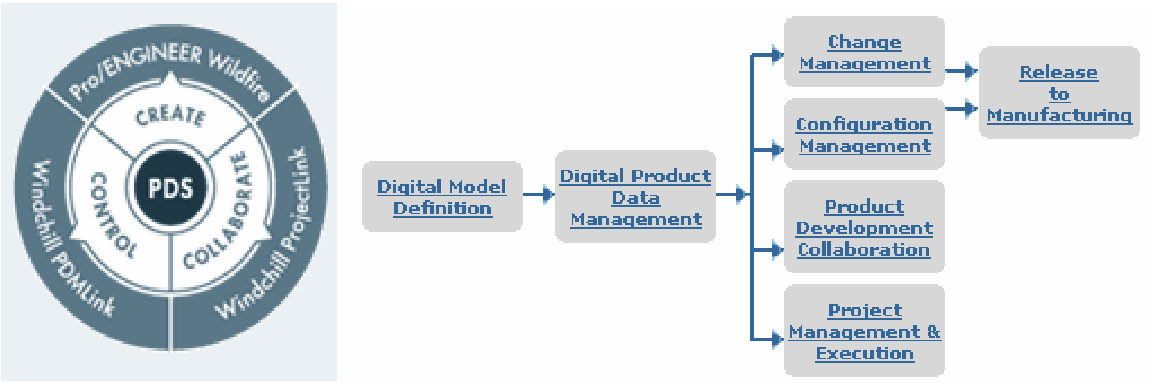

Figure 3.1: PTC's product data management system and fundamentals (www.ptc.com)

Pro/ENGINEER Wildfire supports the digital model definition. Windchill ProjectLink supports project management and execution as well as the product development collaboration. Windchill PDMLink includes the digital product data management, change management, configuration management and release to manufacturing processes.

PTC offers implementation, consulting and training services.

PTC suggests there are five operational areas that must be managed with a PLM implementation (Wrenn, 2005: 1):

1. Targeting the right value opportunity – Two critical elements must be in place for companies to realise the value they want from a PLM implementation program. Firstly, the program must be focused on clearly defined value and secondly, the value opportunity itself must drive program priorities and decisions.
2. Applying a methodical implementation approach – Ensuring that the implementation follows a proven cycle of design, development, and deployment
3. Ensuring end-user adoption – the four areas focused on are:
   - Keep the end users aware of the expected value, timelines, and business impacts of the project
   - Help end users to acquire the necessary skills
   - Help end users to use new applications and skills for their day-to-day activities

- Ensure that the end users can transfer these new skills and applications to any new work or activities

4. Creating a contract for success – Making sure that the mechanics of the written contract reflect the expected value. Thus key considerations should be captured, including expectations for business value, principles for decision-making, executive commitment, performance metrics, project management commitments, accountability measures, and milestones.
5. Strong program governance – A formalized process and structure for setting of priorities, decision-making, and effective change control

The methodical implementation approach consists of the following 5 steps (Figure 3.2):

1. Strategy Development – Create a strategic roadmap that identifies process change, core product development competencies, and enabling capabilities required to achieve business value.
2. Solution Design – Design the solution and implementation plan according to the strategic roadmap
3. Solution Development – Construct the solution according to the design
4. Solution Deployment – Install the production technology, introduce new processes and methods, migrate data, train end users, tune for performance and scalability, and establish the overall support process
5. Value Realisation – Measure and quantify the outcome of the program (or, more granularly, an individual program phase).

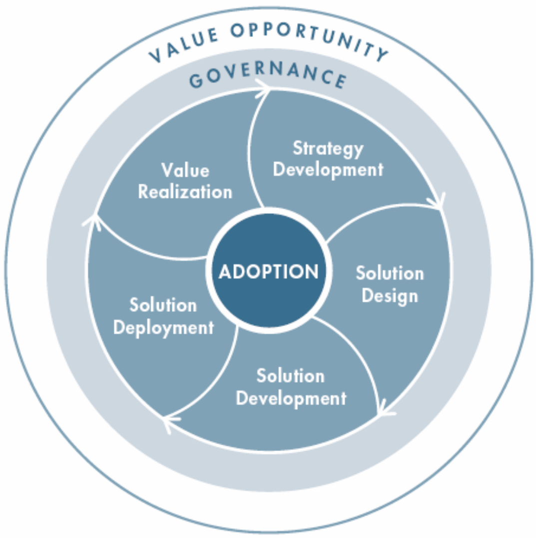

Figure 3.2: PTC's Methodical Implementation Approach (Wrenn, 2005: 2)

PTC's consulting services provide best practices concerning different aspects and challenges in the product development environment and assists with the implementation thereof.

The MatrixOne PLM solution consists of a PLM platform that provides the underlying backbone for the solutions in the following areas:

- Program Management
- Document Management
- Specification Management
- Product Management
- Change Management
- Bills of Material Management
- Supplier Management
- Strategic Sourcing
- Global Collaboration
- Other business processes

The MatrixOne Professional Services organisation employs the Customer Success Methodology™ (CSM) to deliver implementation success. The CSM uses a repeatable, proven process that gears implementation, development and customization services to the client's unique needs, processes and current and future IT infrastructures.

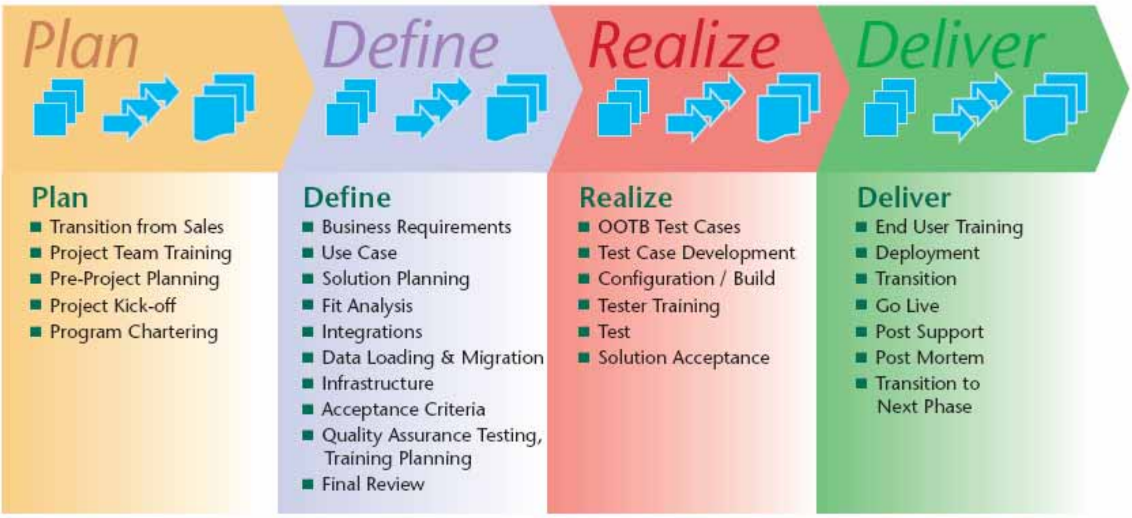

Figure 3.3: The MatrixOne Customer Success Methodology (MatrixOne, 2005:1)

The CSM (MatrixOne, 2005:1) divides projects into phases (Figure 3.3). For each phase, there are three levels of service: infrastructure, development and deployment. Phases and levels can take place in parallel to accelerate delivery.

As part of this service, a Solution Library enables leveraging best practices. Customer training is provided as well as a comprehensive Change Management Plan that is developed to address the five most essential areas for a successful organisational change initiative:

- Leadership Coaching
- Communication Planning
- Workforce Transition
- Organisational Design
- Continuous Improvement

The mySAP Product Lifecycle Management is a part of mySAP Business Suite. The solution map (Figure 3.4) shows the four basic components of mySAP PLM and the business processes supported by each component:

Figure 3.4: SAP PLM solution map
(SAP AG, 2005:1)

The four basic components include (SAP AG, 2005:1):

- Product and project portfolio management
- Life-cycle process support
- Life-cycle data management
- Corporate services

SAP Solution Implementation Consulting provides support for implementation and rollout of new applications using powerful tools, methodologies, process models, and best practices to meet the business requirements. The basic process followed is:

- Analysis and design review: Considers the features and functions of SAP software that are necessary to derive optimum benefits from the investment in SAP.
- Requirements workshops: The business needs are captured so as to determine how to best take advantage of the SAP solution
- Business blueprint: Provides a detailed model of business processes that describes the process needs and points to appropriate solutions
- Process plan: Analyzes the business processes and specifies all enhancements, conversions, interfaces, and reports required for a successful implementation

SAP recognizes that IT investments and projects are measured against their contributions to competitiveness and business value. System architecture, the foundation for a seamless value chain, is critical for allocating and monitoring company resources. Coherent business process design – available through SAP Business Process Design – is a key element in validating the contribution of IT in establishing innovative and flexible processes that support your strategic business goals (SAP AG, 2006:1).

The approach used for business process design is divided into the following phases:

- Calibration phase
- As-is analysis phase
- Business transformation phase
- Implementation phase

The implementation plan is an action plan that includes future steps and milestones as well as change management programs, communication programs and a review process.

The change management focuses on the effects that these changes have on managers and employees. Changes often necessitate new demands in thinking or behaving and new requirements for competencies and skills. The approach defines a change management strategy and concept that provides operating tools and methods to meet six success factors (SAP AG, 2006:1):

- Common orientation
- Conviction
- Ability
- Uniform perception
- Positive results
- Long-term effects

<u>To Summarize:</u>

The implementation approaches of all three available PLM solutions focus on the following:

- The development of a clear strategy/plan for the implementation
- Designing/customizing the solution
- Deploying the software
- End user adoption is ensured through extensive training
- Consultation services are available to assist in implementing best practices and for business process reengineering if necessary.

3.4 CURRENT PLM SOFTWARE IMPLEMENTATION APPROACHES

Implementation approach:

John Stark proposes the following approach for an enterprise-wide PLM initiative (Stark, 2005a: 6):

- Develop and communicate a vision of the proposed new environment.
- Define a strategy to achieve the vision.
- Develop a plan to implement the strategy.

Activities to be addressed in a PDM implementation project are (Stark, 2005a: 383-401):

1. Project start-up:
    - Define objectives, approach, and deliverables. Get top management support.
2. Preparing to select a PDM solution:
    - Consider the current product development process and information environment, the company's business objectives, the user's requirements, the functionality of the system's available.
3. Selecting a PDM solution:
    - Clarify business benefits
    - Identify organisational issues such as training, working procedures, standards and policies defining the use of PDM, and major functional reorganisation.
    - Establish PDM architectures. Key components include the data architecture (flow and structure), the use of data (by function and by system), the structure of the organisation, the structure of control procedures (e.g. release procedures), the information flow network (e.g. sneakernet, ethernet, internet), the lifecycle of projects and products, the computer systems involved and the structure of the PDM support organisation.
4. Implementation and use of PDM:

    The following sequence is suggested for the PDM implementation plan:
    - Process improvement initiatives
    - Get the data under control
    - Implement the information vault and its associated processes.
    - Then address:
        - Product structure management
        - Engineering change management
        - Integration of the PDM system with other company systems such as ERP.

Justification:

It is acknowledged (Stark, 2005b) that the implementation of PLM shows the potential of impacting the bottom-line. At present, cost accounting methods are mostly used to quantify the payback justification.

An example of a typical way of justifying a PLM implementation is (AMR Research, 2003):

- Infrastructure savings. These savings accrue within the first 6 months after implementation and include savings in both IT infrastructure and engineering services, or administrative infrastructure. In most cases a PLM system replaces or at least integrates all the separate systems currently operating in the product lifecycle environment. Much of the interaction between these separate systems is manual, with redundant data entry and hard copies sent via courier being very common forms of integration.

- Improvement in established operating metrics (this usually takes longer to be realised, 6 to 12 months after go-live) which mostly ensure costs savings:
    - Internal improvements in engineering, design, and development processes such as: Change process cycle time reduced, Change process admin expenses reduced, Design errors reduced, Overall engineering administrative activity improved
    - Supplier-facing improvements such as savings on direct material, reuse improved and tooling development lead time reduced
    - Customer-facing improvements that include the reduction of order-to-manufacture cycle time, the reduction of order errors and the reduction of the purchasing order cycle time. This therefore results in an increase in the speed and effectiveness of customer interaction.

- Lastly, the impact of the software on strategic competitiveness (which accrues three to five years after go-live) is included. For example, new markets may be looked at or current market share may be increased substantially.

The justification is made from the point of view that any improvement is an improvement for the company as a whole.

Roll-out strategies:

Two strategies used for the implementation of PLM projects are:
- the “niche project and follow up” approach
- the “overall and step by step” approach

Both strategies have advantages and drawbacks as presented in Table 3.3:

Niche project approach	
Drawbacks	*Advantages*
Difficulty in the following, full scale, project implementation	Motivated and involved personnel are made available, with a driving force effect
Difficulty in evaluating the full scale project involvements	Quick implementation of the technical solution
Project is known only to a few persons	Objective outcome in short term horizon
Few variables are controlled risking conflict arising during the following full scale implementation	Focused resource allocation
Overall and step by step approach	
Drawbacks	*Advantages*
Strong effort due to commitment on many parallel streams	Full scale project defined
A lot of time required for the analysis work	Easiness to evaluate global advantages
Many variables to be managed simultaneously	Project is known to many persons
Unfocused resources allocation	Personnel involved globally
Middle term outcome possible	

Table 3.3: Advantage and drawbacks of PLM roll-out strategies (Garetti, *et al*., 2005:47)

In order to take the opportunity to benefit from the advantages of both solutions, mixed strategies are adopted frequently.

<u>Reasons for implementation failure:</u>

Reasons for failure for PLM implementations include (Stark, 2005a:53):

- Failing to start the initiative properly (no agreed objective, scope or funding)
- Starting the initiative with a preferred information system solution in mind (There was no effort made to understand the real problem to be addressed)
- Believing that implementing a new information system will automatically provide the required results (There was no investment in evaluating how the new system should be used, in training people to use the system effectively, or in defining working procedures)

- Failing to plan properly. (The aim was to implement a computer system as quickly as possible. The system was implemented. There were no real benefits just unexpected costs and problems.)
- Failing to get clear agreement from top management
- Failing to involve middle management (The initiative faded away when department managers felt that the result of the project would cause them to loose power.)
- Failing to involve all participants (The Research and Development Department chose a particular system. When it was implemented, other departments refused to use it, as they had not been consulted about the choice)

Chapter 4:

TOC, A HOLISTIC APROACH

4.1 ANALYSIS TOOLS

Theory of Constraints (TOC) is a holistic management philosophy. TOC is a systems philosophy, thus it considers an organisation of any kind as functioning as a system, not as a collection of separate processes (Schragenheim, 2000:13). Every system has a goal. The goal of for-profit companies is to "make more money, now and in the future" (Schragenheim, 2000:24). Achievement of the goal is measured by increased profits.

A constraint is defined as anything that limits a system's higher performance relative to its goal (Scheinkopf, 1999: 15). TOC claims that the throughput of a system is governed by very few elements, referred to as constraints. From a physical point of view, the governing element is the weakest link in the system and from a logical point of view the governing element is the core problem (Figure 4.1). These constraints are the leverage points that, if addressed, will result in a holistic improvement of the system.

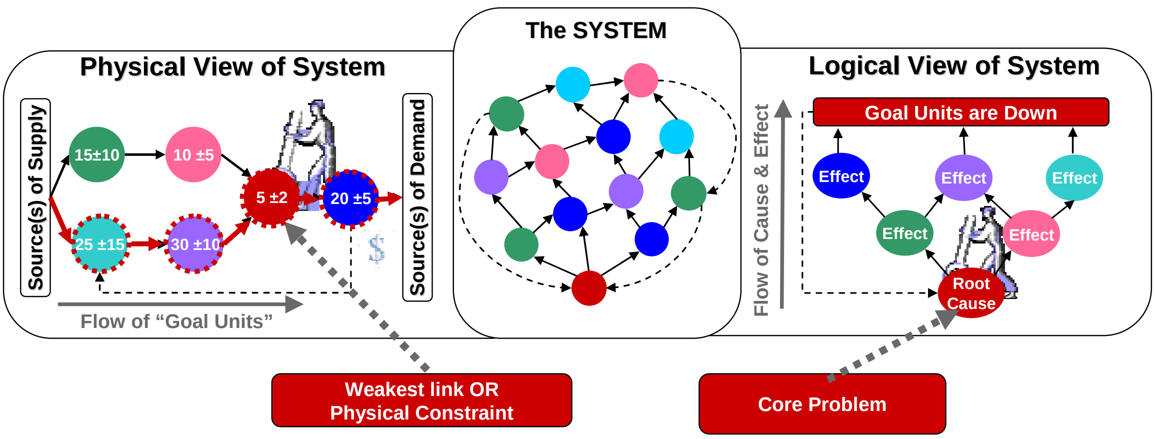

Figure 4.1: Logical and physical leverage points (Goldratt *et al.*, 2004)

TOC employs two sets of analysis tools: the TOC thinking tools and the 5 focusing steps. These two sets examine a system from a logical point of view and from a physical point of view respectively.

TOC analysis tools have been positioned in relation to traditional Operations Research/ Management Science methods and methodologies. It has been proved that TOC offers Operations Research/ Management Science practitioners a set of methods worthy of consideration for use alongside traditional Operations Research/ Management Science methods and tools (Mabin *et al.*, 2005:507).

4.1.1 A logical analysis of a system

The logical analysis of a system begins with the identification of the undesirable effects that are being experienced by the different parts of the system. **U**n**D**esirable **E**ffects (UDEs) are symptoms or negative effects experienced in current reality. These effects are undesirable, because they inhibit the better achievement of the goal of the system.

A UDE should be verbalized according to the following criteria:

1. It is a complete statement
2. It exists in current reality
3. It is an "effect", not a presumed "cause"
4. A single effect, without an "and," "because" or "as a result of."
5. It is negative in its own right and can be quantified or at least qualified
6. There is agreement that it is very important to remove it (has a significant negative impact on Goal Units - Sales, Costs and or Investment)
7. It does not blame anybody directly, but describes the undesirable effect being experienced

The cause and effect relationships between the UDEs from the different functional entities are built in order to identify the core problem that causes most of the undesirable effects. In other words, UDEs exist due to the existence of a problem.

The focus on finding the core problem stems from a fundamental principle of TOC (Necessary but not Sufficient CD Series: *The basic assumptions of TOC*. 2002) which declares that inherent simplicity exists in any system. TOC is based on the hard sciences approach to complexity, which states that: the more degrees of freedom a system has, the more complex the system is (Figure 4.2). This is opposed to the general definition of complexity that defines a complex system as being a system that needs more data elements to fully describe it

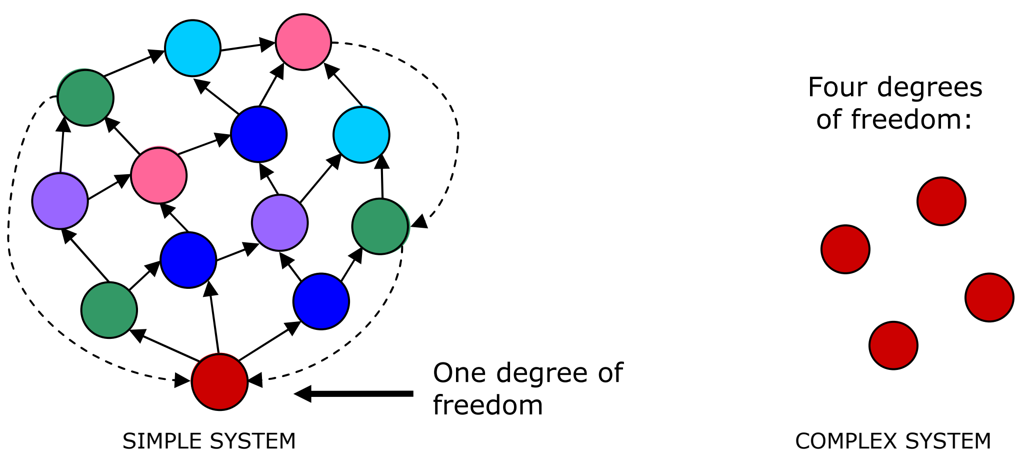

Figure 4.2: A simple and complex system

The conviction that inherent simplicity exists in any system is made practical through the use of the cause and effect logic tools. These tools make use of sufficient cause thinking. Sufficient cause thinking is used when it is assumed that something is the inevitable result of the mere existence of something else (Scheinkopf, L. 1999: p. 31). The Current Reality Tree (CRT) is essentially a map of the cause and effect relationships perceived to underlie the current undesirable situation, with cause and effect entities depicted as boxes linked by directional arrows to reflect the logical relationships (Mabin *et al*., 2005:515).

The current reality diagram should be read from bottom to top using if-then logic. Thus, referring to Diagram 4.1, the CRT should be read as follows: If A then B. If B and C then D.

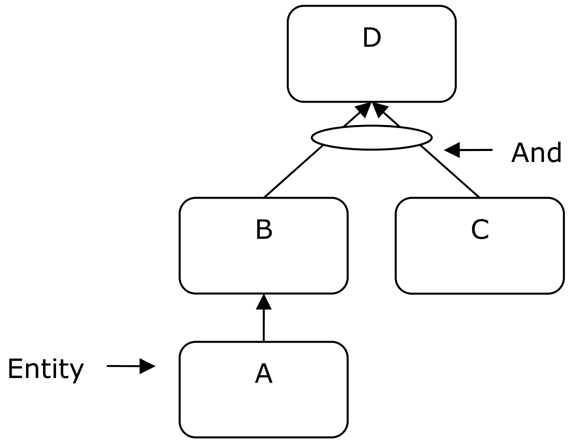

Diagram 4.1: A CRT diagram

Another thought pattern that TOC applies is necessary condition thinking, which is used when thinking in terms of requirements (Scheinkopf, L. 1999: p. 69). This is applied in the TOC analytical tool called the Evaporating Cloud/ Conflict Diagram. This tool is used to define core problems and represents the practical application of another fundamental principle of TOC (Necessary but not Sufficient CD Series: *The basic assumptions of TOC*. 2002). TOC, like the natural sciences, assumes that reality has no conflicts. A general definition for a problem is something that is disliked. The hard sciences, however, define a problem as being the conflict that prevents the system from reaching its objective. In the natural sciences no compromises will be made and therefore if a conflict is discovered, it means that the assumption that was made about reality was wrong.

The Conflict Cloud diagram defines a problem. The tool is then used to uncover the assumptions that are made about reality that support the existence of the problem. The contradiction of an assumption provides the breakthrough solution or injection.

The Conflict Cloud method is based on the following formulation of a problem (see Diagram 4.2): A problem exists whenever there is something that prevents/limits the fulfilment of a desired objective. The type of problems usually dealt with involves at least two requirements or system needs that must be satisfied. These system needs are both legitimate needs. To satisfy each requirement/need an action or prerequisite must be met. The conflict exists in the actions taken to meet the legitimate needs.

The conflict cloud diagram should be read as follows (refer to Diagram 4.2): In order to meet the objective A, the requirement B must be met. In order to meet the requirement B, the action D must be taken. On the other hand, in order to meet the objective A the requirement C must also be met and in order to meet requirement C the action D' must be taken.

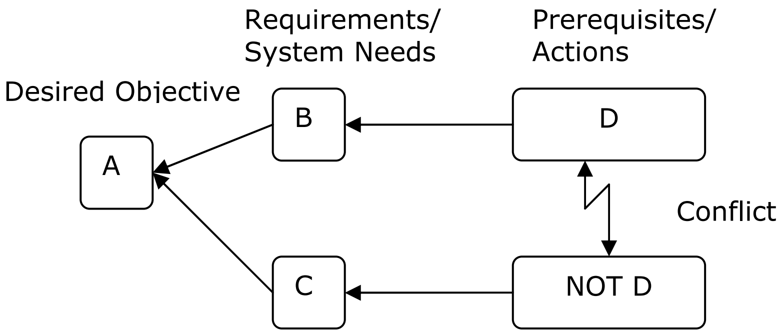

Diagram 4.2: An evaporating cloud

The assumptions are uncovered at every arrow linking two entities, for example (refer to Diagram 4.2): In order to meet B, the action in D must be taken, because of certain reasons. These reasons are the assumptions for the arrow BD. If one of these assumptions can be invalidated then the cloud can be evaporated and a direction for a solution can be found.

The Current Reality Tree (CRT) and the Conflict/ Evaporating Cloud are tools that are used to identify core problems within an environment. The primary injection or action emerging from the Evaporating Cloud analysis is used for the development of the solution.
The primary injection and the supporting injections are portrayed in a Future Reality Tree (FRT). It is those actions or solutions which, if completely defined and implemented, would eliminate the core problem(s), thus causing significant improvement in achieving the organisation's goal.

The Future Reality Tree (FRT) is another cause and effect logic tool which is similar to the CRT, but it only depicts the future desirable situation. The injections, together with desired effects, (as opposed to undesirable effects) are the building blocks for an FRT. The verbalization of a desired effect is usually done in such a way that it shows that the effect will be continuously improved, i.e. rework will become less and less.

Other TOC tools are the Prerequisite Tree and the Transition Tree. These tools are typically used to develop the necessarily comprehensive implementation and buy-in plans (Cox *et al.*, 2005:40).

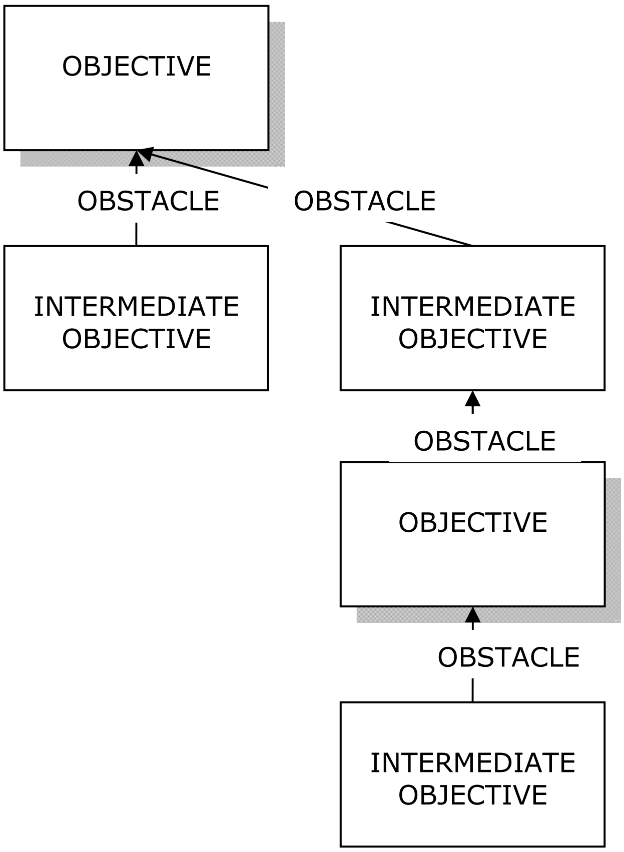

Diagram 4.3: A prerequisite tree

The prerequisite tree is a diagram that describes the necessary condition relationships that are involved in achieving objectives. Necessary condition thinking is applied. The entities in the diagram include the following (diagram 4.3):

- Objective: a goal of the prerequisite tree
- Intermediate Objective: These can be described as milestones that must be reached in order for the objectives to be achieved.
- Obstacle: the arrow identifies a necessary condition relationship between two entities i.e. the entity at the base of the arrow must be in existence before the entity at the point of the arrow will be allowed to exist. The assumption behind the dependency is the obstacle, which is stated right on the arrow. Unless the obstacle in the current reality is overcome the objective will not be achieved (Scheinkopf, L. 1999: p. 195).

The transition tree is a sufficient cause diagram used for creating action plans. It defines the specific steps (actions) that will transform the current reality into a specific future reality (objectives) (Scheinkopf, L. 1999: p. 85).

A simple transition tree is presented in Diagram 4.4:

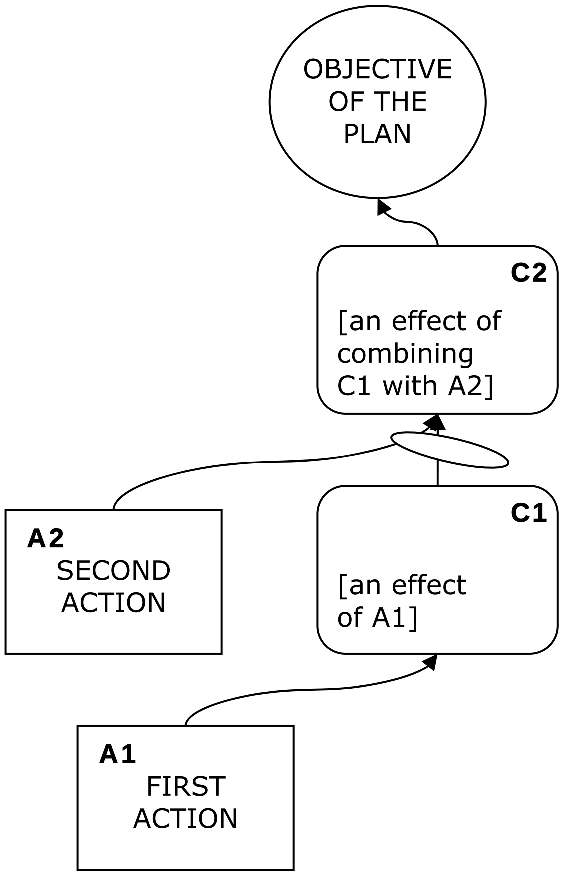

Diagram 4.4: A simple transition tree

4.1.2 The physical analysis of a system

The set of thinking processes is one of the TOC processes for on-going improvement. The other set is the Five Focusing Steps and is usually applied in the physical analysis of a system. The Five Focusing Steps are:

1. Identify the system's constraints.
2. Decide how to exploit the system's constraints.
3. Subordinate everything else to the above decision.
4. Elevate the system's constraints.
5. If in the previous steps a constraint has been broken, go back to step one, but do not allow inertia to cause a system constraint.

Consider the following representation of a physical system (Figure 4.3):

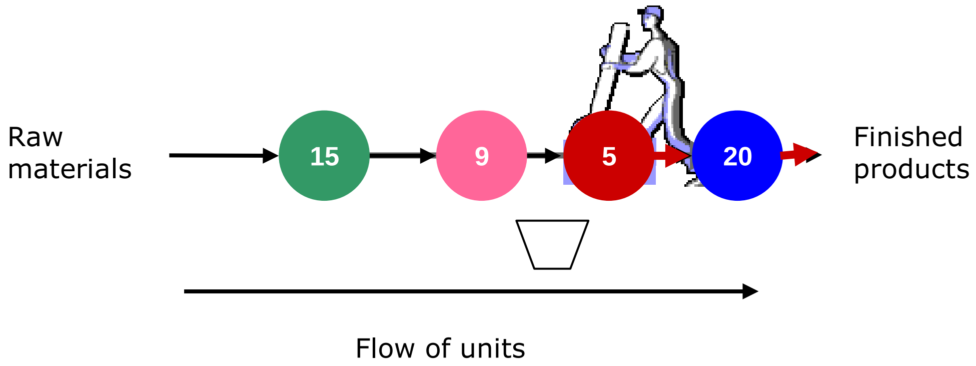

Figure 4.3: A representation of a physical system

The coloured circles represent resources. The number on the circle represents the units/hour that the resource can process. The constraint (weakest link) of this system is the red resource with the capacity of only 5 units/hour. The constraint governs the throughput of the system. Exploitation decisions are decisions that are made in order to get the maximum potential out of the constraint. Subordination is the implementation of these exploitation decisions.

An example of an exploitation decision is the reduction of stoppages of the red resource. This is achieved through the subordination of the operators to the constraint by planning their lunch breaks in such a way that there is always an operator available to operate the red resource.

Ensuring that there is buffer stock in front of the bottleneck resource is another way of reducing the stoppages of the red resource. The stock buffer enables the red resource to carry on working when a breakdown has occurred at one of the upstream resources. After the breakdown, the resources upstream from the constraint must rebuild the stock buffer. This is only possible if they have more capacity than the constraint. The excess capacity of non-bottleneck resources is referred to as protective capacity. (If non-bottleneck resources have 20% more capacity than the bottleneck, it means that after a breakdown the non bottleneck resources will take five times longer than the time of the breakdown to build up the buffer stock.) Should a breakdown occur, non-bottleneck resources having 20% more capacity than the bottleneck, will take five times longer than the time taken by the breakdown to build up buffer stock. In TOC the throughput of the system is protected with stock buffers and protective capacity (as illustrated in the abovementioned example). The third form of protection is time buffers, which is the set time period material is released before the constraint/bottleneck needs it.

Elevation is only considered after the constraint has been fully exploited. An example is investment in another red resource. Investment in another red resource will increase the capacity of this operation to 10 units/hour. Thus the new weakest link is the pink resource with a capacity of 9 units/hour. When the constraint moves, the five focusing steps must once again be applied. Thus when the constraint has moved, all the decisions that were made for the previous constraint must be reconsidered and changed.

A summary of the analysis tools is given in Table 4.1.

TOC uses a process for buy-in that is designed to overcome resistance to change and increase the probability of success when presenting a solution.

The layers of resistance are (Kendall, 2005:98):

1. People do not agree on the problem
2. People do not agree on the direction of the solution
3. People do not agree that the proposed solution will overcome the problem
4. People agree, but there are negative consequences
5. People agree, but there are obstacles that might block the implementation

To overcome resistance to change and achieve buy-in the following structure should be used when presenting a solution or offer:

1. Get agreement on the problem
2. Establish agreement on the direction of the solution
3. Agree that the solution will yield the desired effects
4. Identify negative effects
5. Identify the implementation obstacles

Methodology / Technique	Current Reality Trees	Evaporating Clouds	Future Reality Trees	Transition Trees	5 Focusing Steps
What it does A System to . . .	. . . search for root causes, and explain how these lead to problem symptoms	. . . represent explicitly one or more persons' conflicting views	. . . determine effects and outcomes following from proposed actions and solutions	. . . identify required actions to generate desired outcomes and results	. . . identify and manage constraints on continuous improvement
What it assumes to exist	Problems, symptoms, cause–effect relations	Individual beliefs about competing views and the assumptions underlying these views of different stakeholders	Problems, actions, desired outcomes, outcomes, cause effect relations	Problems, actions, desired outcomes, outcomes, cause effect relations	Constrained performance, barriers to improved performance
Representation by modelling . . .	Cause–effect/logic relationships	Seemingly diametrically opposed viewpoints, underlying assumptions and relevant stakeholders	Cause-effect/logic relationships	Cause-effect/logic relations in the form of a map, actions, desired outcomes	Process of identifying and examining constraints on performance
Necessary Information	Objective facts, subjective opinions, logic relations, perceptions, judgments, patterns of behaviour	Options, stakeholder viewpoints, and their interests	Objective facts, subjective opinions, logic relations, judgments	Objective facts, subjective opinions, logic relations, judgments, desired outcomes, actions to achieve them	Objective facts, opinions, logic relations, judgments, desired outcomes, actions to achieve them
Source of information	Observation and measurement of real world, logic relations, judgment and opinion	Interviews, discussion, argument, debate with participants, analyst's reasoning	Observation and measurement of real world, judgment	Observation and measurement of real world, judgment and opinion	Observation and measurement of real world, judgment and opinion
Users	Decision-maker, analyst, consultant, facilitator, participant	Analyst, participant	Decision-makers, analyst, consultant, facilitator, participant	Participants, decision implementers, stakeholders	Participants, decision makers and implementers, stakeholders
Purpose in order to . . .	. . . discover root causes to problems	. . . surface and understand individual beliefs, synthesize competing viewpoints, explain how these lead to conflict, generate actions to resolve conflict	. . . show how actions lead to desired outcomes	. . . to create an action plan to achieve desired outcomes	. . . to improve global performance long-term

Table 4.1: TOC thinking process summary

(Mabin *et al.*, 2005:510)

4.2 CRITICAL CHAIN PROJECT MANAGEMENT

There are TOC solutions that address the typical problems associated with areas such as operations, distribution, marketing, sales and projects.

The Critical Chain Project Management (CCPM) solution is used as an example to illustrate the use of the TOC analysis tools. More specifically, the definition of a core problem and a holistic management solution is presented.

Three factors play a role in every project, namely: scope, time and budget. The protection of one of the factors usually leads to a compromise in the other factors, e.g. the scope of a project is protected thus rework is allowed. As a result the project budget and timeframe is compromised.

Typical undesirable effects that exist in a project environment today are (TOC Insights into Project Management, 2003c):

- Due dates are often not met
- There are too many changes
- Too often resources are not available when needed
- Necessary things are not available on time (information, specifications, materials, designs, authorization, etc.)
- There are fights about priorities between projects
- There are budget over-runs
- There is too much rework

The core problem of the current project management environment is presented. It also demonstrates the Evaporating Cloud analysis introduced in the previous section (refer to Figure 4.4):

In order to meet original commitments (A) there is a need to do whatever it takes to meet the endangered original commitment (B). In order to do whatever it takes to meet the endangered original commitment (B), compensation must be made for the incorrect estimations that were made initially (D). On the other hand, in order to meet original commitments (A) there is a need to ensure that no other original commitments are jeopardized (C). In order to prevent jeopardizing other original commitments (C) no compensation must be made for incorrect estimations that were made initially (D’).

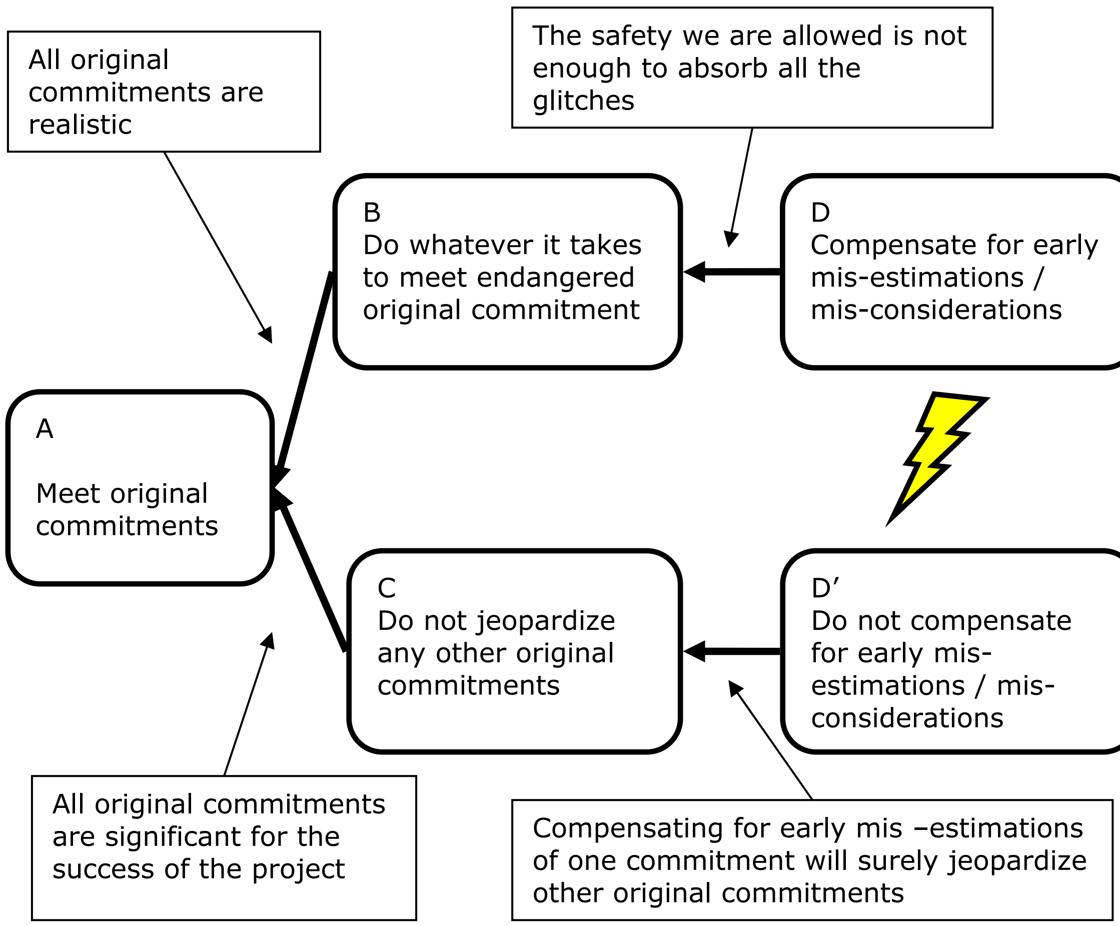

Figure 4.4: The project management core conflict (TOC Insights into Project Management, 2003c)

The assumption between B and D is uncovered as follows: in order to do whatever it takes to meet the endangered original commitment (B) compensation must be made for the incorrect estimations that were initially made (D). This is because the safety included in the project is not enough to absorb all the glitches (Assumption BD).

The assumption between C and D′ is uncovered as follows: In order to prevent jeopardizing other original commitments (C) no compensation must be made for incorrect estimations that were made initially (D′). This is because compensating for the incorrect estimations of one commitment will surely jeopardize other original commitments (Assumption CD′).

The assumption between A and B is uncovered as follows: In order to meet original commitments (A) there is a need to do whatever it takes to meet the endangered original commitment (B) because all the original commitments are realistic (Assumption AB).

The assumption between A and C is uncovered as follows: In order to meet original commitments (A) there is a need to ensure that no other original commitments are jeopardized (C) because all original commitments are significant for the success of the project (Assumption AC).

The assumption between B and D is challenged, because enough safety is embedded in tasks. However, the safety is wasted due to the following modes of operation:

1. Student Syndrome: The start of a task is delayed until much later than originally planned.
2. Parkinson’s Law: Work expands to fill the time available for its completion
3. Bad Multitasking: Multitasking becomes a problem when the lead-time to complete a task is significantly longer than the actual time invested in doing the task.
4. Integration of project tasks is problematic when delays are transferred to the next task in full, but gains are not.

These modes of operation are caused by holding people accountable for their task estimates. In other words, the core problem is the common belief that the way to ensure a project finishes on time is to make sure that every task finishes on time.

Critical Chain Project Management (CCPM) is the solution to this core problem. This is illustrated through a short explanation of the basic principles of CCPM (Patrick, 2000).

CCPM shifts the focus to the project due date. It requires the elimination of task due dates from project plans (which is the first step in overcoming Parkinson’s Law).

Project tasks are subject to considerable uncertainty. The uncertainty exists due to both the unknowns associated with the invention process (especially in development projects) and from the universal effects of "Murphy's Law." As a result, task estimates that make up project schedules can contain considerable "safety". The safety for a task is further expanded due to multitasking, which is a reality in multi project environments. Multitasking leads to expanded project lead times because when a resource alternates between tasks/projects, the task times for an individual project are expanded by the time that is spent on the other projects' tasks. The combination of the effect of the multi-tasking environment and the need to cover uncertainty lead to "realistic" project task estimates that contain considerable "safety" above and beyond the actual work time required for a task.

The CCPM approach addresses this expansion of project plans by removing the safety from the tasks, and aggregating it as "buffers" of time. The buffers are sized and placed in the schedule to protect the final due date of the project from variability in critical tasks. In addition, feeding buffers protect critical tasks from variability in non-critical tasks that feed them. Thus the task time estimates are shortened to aggressive target durations (approximately 50% of the given estimates). This leads to a decrease in the time within which resources strive to achieve their tasks. Furthermore, projects/tasks are pipelined, thus preventing multi-tasking or other distractions.

4.3 THE ROLE OF MEASUREMENTS

The traditional approach to improving and managing a system is to dissect a system into smaller, more manageable parts. If the system considered is a company, then it is dissected into different departments/functions. Each department is measured on its own performance and improvements are focused locally. The belief is that an improvement in a department will amount to an improvement for the company as a whole (TOC Insights into Finance and Marketing, 2003b). Stated differently, the functional approach assumes a global improvement is the sum of all the local improvements. In other words, the additive rule applies. Cost obeys the additive rule. The functional approach to the management of an organisation is enforced by measures for which improvement means a focus on cost reduction or greater efficiency within a department (Kendall, 2005:24).

Measuring departments separately can, however, lead to a situation where improvements gained in one area of a business are at the expense of another area of the business. Examples are (Smith 2000: iii):

- Achieving inventory reduction goals, results in stock outs and delays in manufacturing
- Cutting costs leads to quality problems or the ability to deliver on time is hampered
- Expediting to ensure that one product or project is on time causes others to be delayed

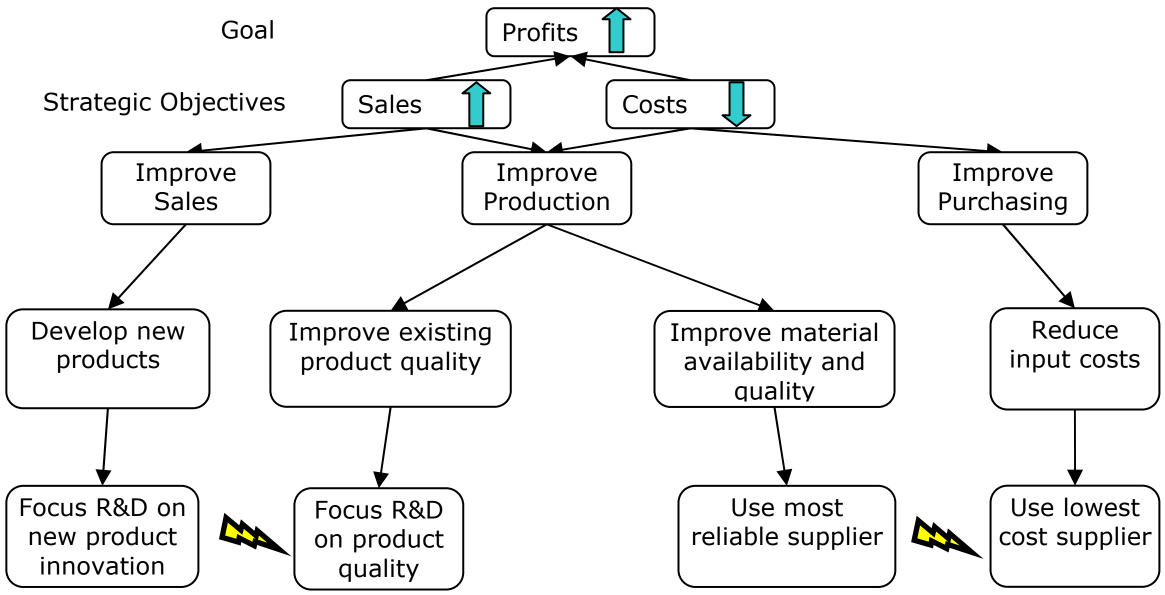

Figure 4.5: Inherent conflicts
(Goldratt *et al.*, 2004)

Another negative is inherent conflicts that are created between the different functions/ departments. For example (refer to Figure 4.5) a purchasing department policy is reducing input costs, therefore they want to use the lowest cost supplier. On the other hand, a production policy is to improve material availability and quality. Therefore the production department wants to use the most reliable supplier. The most reliable supplier is not necessarily the lowest cost supplier, thus a conflict exits due to conflicting policies and measures. Policies can also cause conflicts due to the scarcity of resources. On the one hand, the Research and Development (R&D) department is asked to focus on developing new innovative products in order to improve sales. On the other hand, the R&D department is pressured to improve the quality of existing products to improve production.

The functional and cost accounting approach can be explained using the following analogy: an organisation is a chain and the different departments are the links in the chain. The weight of the chain obeys the additive rule; the sum of the weights of all the links equals the weight of the chain, thus improvement in the weight of one link contributes to the improvement in the weight of the whole chain (TOC Insights into Finance and Marketing, 2003b).

Throughput accounting, however, is based on the premise that a cost saving in one part of the company might negatively influence the company as a whole. Throughput does not obey the additive rule. In the chain analogy throughput is represented by the strength of the chain. Improving the strength of any link of the chain does not necessarily lead to the improvement of the whole chain. A chain is always only as strong as its weakest link.

Throughput accounting and TOC focuses on Throughput. There is a term for the paradigm that stresses a strategic emphasis on throughput: the Throughput World Paradigm (Newbold, 1998: 35). This is opposed to traditional accounting and management that focuses on cost-savings: the "Cost World paradigm".

Goss defined a paradigm as "a constellation of concepts and values shared by a community of people. The paradigm is an invisible cultural structure through which we see the world; a lens so transparent that we are unaware that we are looking through it, therefore we are unable to see how it distorts our perceptions" (Goss.1996:73).

TOC claims that a change to most of the variables in an organisation will only have a small impact or no impact on the global performance. There are very few variables, perhaps only one, where a significant change in local performance causes a significant change in global performance. Such a variable is called a constraint (the weakest link). Thus better achievement towards the company's goal is done by identifying the constraint and then improving its performance.

TOC recognizes that every system was built for a purpose. Thus, every action taken by any part of the organisation should be judged by its impact on the overall purpose (holistic approach).

Measurements are the primary method of accounting for the results of actions being taken within an organisation. Measurements come from formal and/or informal policies, which in turn are based on the operating assumptions held about reality. Measurements can be considered to be an output of a system because they are the primary source of feedback to managers and workers alike.

However, measurements also act as an input. They have considerable influence on the actions that employees choose to take in the first place. Since measurements are usually formally (or informally) tied to performance evaluation, workers tend to try and do more of whatever has a positive impact on their measurements, and less of whatever has a negative impact. Measurements and rewards tell employees what is the right thing to do and this is portrayed by the quote: *"Tell me how you measure me and I'll tell you how I'll behave."* (Smith 2000: vii).

Conventional management approaches use many, sometimes complex, measures to manage the different parts of the system: An example of the suggested measurements to be used in the product development environment is included in Appendix 1: Traditional Product Development Measurements.

TOC however only makes use of a few holistic measurements to manage a whole system. The basic measurements are:

1. Throughput (T):

   Throughput is defined as the rate at which money is generated by the system through sales. From an operational point of view it is measured as units/hour and it determines the flow rate of a system. The goal is to increase T.

2. Investment (I):

   Investment is all the money that the system has invested in purchasing things it intends to sell. This includes Work in Process (WIP).
   Little's law provides the means of determining the amount of inventory in the system using the flow time and flow rate of the system. The amount of inventory in a system is equal to the flow rate (F_R) multiplied by the flow time (F_L) (refer to Figure 4.6)

   Thus: $I = F_R \times F_L$

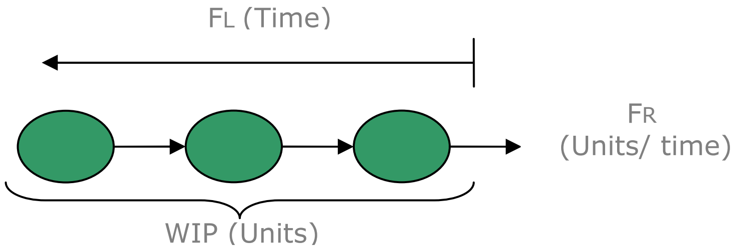

Figure 4.6: Little's law

The flow time of a system is the same as the lead time (Lt) of the system. As mentioned above the flow rate of a system is the same as the T of the system. These two measures multiplied give the amount of inventory or WIP in the system. Thus: WIP= T x Lt

WIP and Lt are directly proportional; an increase in the lead time of the system results in an increase of the WIP in the system. The goal is to reduce the inventory in the system. Thus Lt must be reduced.

3. Operating expense (OE)

OE is all the money that the system spends to turn inventory into throughput.
The goal is to minimize OE.

4. Throughput Rand Days (TRD)

TRD is a measure of reliability. It is determined by multiplying the Rand value associated to not meeting a commitment, with the time that the commitment is delayed. The goal is to achieve a zero TRD value. This measurement is mostly used to measure the reliability of the distribution system but can also be used to measure the reliability of tasks in a project related environment (TOC Insights into Distribution, 2003a).

In a project environment TRD quantifies the impact of buffer consumption (resources should be measured on the extent to which they use up buffers.). It is assigned to the person/team responsible for the lateness and equals the Throughput (T) Figure of the project (entire project selling price) times the amount of days of buffer that has been consumed (RD).

5. Inventory Rand Days (IRD)

IRD is used as a secondary measure to TRD to measure the effectiveness of a distribution system. It is calculated by multiplying the Rand value of the inventory at hand by the time the inventory entered the responsibility of the link. The goal is to have the minimum IRD needed to ensure system reliability (TOC Insights into Distribution, 2003a).

6. Quality On Time In Full (QOTIF)

   QOTIF measures adherence to schedule. It promotes the improvement of quality and Due Date Performance (DDP).

7. Buffer status

   TOC makes use of time buffers and stock buffers. Buffers are usually divided into three sections - a red, yellow and green section. A buffer penetration between 67% to a 100% is the red zone and indicates that the time or stock protection is low. Buffer status, which measures the penetration into a buffer, is used to provide clear priorities between different tasks or works orders. The task with the highest buffer penetration should be completed first.

<u>Making Investment Decisions:</u>

Traditional investment decisions are focused on cost savings. When considering a new piece of equipment the logic followed is typically (TOC Insights into Finance and Measurements, 2003b):

1. Determine the time saved per part/task
2. Translate time saved per part/task into time saved per year
3. Translate time saved per period to money saved per period (cost saved per hour is taken as e.g. direct labour and overheads)
4. Calculate Return On Investment (ROI)
5. Compare the ROI to the company standard ROI. If it is equal or less than the standard then the investment is justified.

TOC, however, draws attention to the following: If the bottleneck of a process governs the throughput of the process, then investment in a non-bottleneck resource will not save costs. This is because new equipment rarely reduces overhead (transferring employees to other departments does not reduce cost). In addition, activating a non-bottleneck as much as possible in order to justify it, will not lead to increased sales but only to high-levels of WIP. If the investment is made to increase the capacity of a bottleneck resource, then the increase in bottleneck production implies an increase in products that can be sold. Thus T increases, which has a direct impact on the bottom-line.

The performance measurements used to verify whether the company is moving towards its goal are NP and ROI. Throughput Accounting calculates Net Profit (NP) by subtracting the operating expenses from the throughput, thus NP = T-OE. Return on Investment (ROI) is calculated as the net profit divided by the investment, thus ROI = NP/I. Therefore the three global parameters T, I and OE enable the measurement of the global impact of any management decision.

Chapter 5:

THE N&S SOLUTION AND APPLICATIONS

5.1 THE N&S PRINCIPLES

Goldratt approaches the aspect of implementing and using new technology in his book *Necessary but not Sufficient*. He makes use of simple statements to distinguish between the concepts of necessity and sufficiency relevant to the implementation of software. These statements are practically implicated by simple questions that should be answered in order to help achieve the successful implementation of new technology.

In this section the following elements are discussed:

1. The statement: Technology can bring benefit if, and only if it diminishes a limitation.
2. The statement: Technology is necessary but not sufficient.
3. Questions that can facilitate the process of achieving full-benefit from the implementation of new technology.

Definitions were developed for the central concepts of the N&S solution. The definitions are given in the following section.

5.1.1 Exploration of the concept of the necessity of technology:

Technology can bring benefit if and only if it diminishes a limitation

This statement makes use of the two words: benefit and limitation. If the acquisition of new technology is perceived as the improvement of a system with defined boundaries, goals, and measurements, then limitation and benefit can be defined as follows:

Limitation: A limitation is anything that prevents a system from achieving higher performance towards its goal.

Benefit: Benefit is achieved when a change causes a better achievement of the system’s goal.

The assumptions, on which the statement is based, are:

1. If the technology does not diminish any limitation whatsoever, it cannot create benefits
2. If something is a limitation by definition it means that diminishing it brings benefits.

Thus, in order to achieve benefit from the implementation of technology, the implementation has to cause a better realisation of the system's goal. However, in order achieve this, something that prevented the system from achieving a better realisation of its goal, a limitation, has to be diminished.

When considering a new technology, this statement and its assumptions, implies that new technology should only be considered if it will diminish a limitation. If the new technology does not diminish a limitation, it will not bring any benefit. Subsequently, if the new technology does not bring any benefit, then it is not necessary.

The concept of necessity, in the context of implementing new technology, can be defined as:

Necessity: Something (an activity / a change / new technology) that brings benefit by diminishing a limitation.

5.1.2 Exploration of the concept of the sufficiency of technology:

Technology is a necessary condition but it is not sufficient.

Goldratt states that the existence of the limitation is recognized and accommodated by customs, habits, measurements, policies, behaviours and measures (Goldratt *et al.*, 2000:125). If, as part of the implementation, these modes of behaviour (from now on referred to as rules) are not addressed, the new technology will be used in an environment that still assumes the existence of the limitation. Therefore, the rules will impose a limitation. If these rules are not changed, the full benefits of the new technology will not be realised.

The concept of sufficiency creates awareness of the additional activities/aspects that are necessary to ensure the successful implementation of technology. Goldratt focuses on the activity of changing those rules that recognize the existence of the limitation.

The following definition of sufficiency has been formulated:

Sufficiency: An improvement process is sufficient when all activities or aspects within the boundaries of the system, that bring benefit by diminishing a limitation, have been exploited. Therefore, an improvement process is sufficient when all the necessities have been exploited.

This leads to a definition of full benefit:

Full benefit: When an improvement process is sufficient, it means that nothing else can be done to achieve a better realisation of the system's goal; therefore full benefit has been achieved from the improvement effort.

5.1.3 Achieving bottom-line benefit:

Goldratt formulated four questions that should be answered to ensure that we achieve bottom-line benefit from the implementation of new technology:

1. What is the main power of the technology?
2. What limitation does this technology diminish?
3. What rules helped us to accommodate the limitations?
4. What rules should we use now?

Questions one and two focus attention on the necessity of the technology. They are based on the statement that technology can bring benefits if, and only if, it diminishes limitations.

With questions three and four Goldratt focuses on the activity of changing the rules that recognize the existence of the limitation when a new technology is implemented. In the book, *Necessary but not Sufficient*, and the Necessary but not Sufficient CD Series, Goldratt establishes the changing of the rules as a necessity that should be addressed to achieve more benefit from the implementation of a new technology. This activity can consist of a slight change in the rules or even a replacement of the old rules with new ones.

The sufficiency of the implementation of the new technology can only be justified if all the necessities associated with the implementation of the new technology has been identified and utilized. Full benefit can only be realised when the improvement effort is sufficient.

The ultimate goal of the implementation of new technology (an improvement effort) should be to achieve full benefit.

Additionally, the following two questions can be answered:

5. In the light of the changes in rules, what changes are required to the technology?
   The insights gained from answering the first four questions can be used to provide recommendations to the software provider as to which features might be necessary and which features are redundant.

6. How to cause the change (the new win/win business model)?
   The last question is asked in order to ensure that no inherent conflicts exist between the implementer, service provider and the customer. Thus they are all aligned to achieve the same goal and are measured accordingly.

This thesis only focuses on the answering of the first 4 questions.

5.2 STUDY OF THE EXISTING APPLICATIONS OF THE N&S PRINCIPLES

The N&S Solution was applied to the implementation of MRP and ERP. The following section summarizes Goldratt's discussion of the role of software in the Necessary but not Sufficient CD Series.

5.2.1 What is the power of the technology?

The answers to the first question for the technologies of MRP and ERP are:

- The power of MRP is the ability to do dependant calculations.
- The power of ERP is the ability to handle large amounts of data, transfer data between departments, and the ability to retrieve data quickly and effectively.

The concept of the power of the technology refers to the capability of the software, i.e. what the software can do with the provided data.

5.2.2 What limitation does the technology diminish?

The answer to the second question for the technology of MRP is: MRP diminishes the limitation of doing net requirements manually.

MRP (material requirements planning) in its basic form is a computer program determining how much of each item is needed and when it is needed to complete a specified number of units in a specific time period.

Before MRP utilisation, several employees were dedicated to do these net requirement calculations. Calculating net requirements was such a time-consuming job that, at the very most, it was only done once a month.

It is important to note that the calculation of net requirements once a month affected the way businesses were run. Certain policies and modes of behaviour developed due to this limitation. For example, if the net requirement calculations were only done at the end of each month, this meant that the material requirements were fixed for the next month. Therefore, if an order was placed during a particular month, the planning for the order was only carried out at the end of the month during which the order was placed. Therefore, undersupplied materials were ordered at the end of the month. Only when these materials were received, could the production for customers begin. Consequently, it was common practice to fulfil customer orders only in two to three months' time.

MRP makes the calculation of net requirements easier and faster. By using MRP it is possible to do the net requirements much more frequently, e.g. overnight. This provides a more exact representation of the current materials situation in the plant and hereby faster fulfilment of customer orders can be ensured.

The answer to the second question for the technology of ERP is: ERP diminishes the limitation of making management decisions without having all the relevant data.

It is important to recognise that not having access to all the relevant data affected the way decisions were made and ultimately the way businesses were run. This was a limitation in the system. Certain policies and modes of behaviour developed due to this limitation and they were developed to facilitate the making of decisions without having all the relevant data.

Before ERP utilisation, it was an effort to get data from different departments or even from different workstations. All data was not stored at one accessible place. Therefore, acquiring data meant that an employee physically had to go to the area from which the data was required and that enquiries had to be made for the relevant information. From here, another employee had to search through conventional (paper) filing systems to retrieve the relevant information for further use. This was an almost impossible or at best a tedious task. Therefore, in practice, only local data was available and could be used to make decisions.

Goldratt (Necessary but not Sufficient CD Series: The Role of Software) uses the following example to illustrate the above-mentioned concept: A supervisor of a workstation has to make a decision: a stack of inventory is waiting at a workstation to be processed. Without knowledge of what is happening in the rest of the plant, the best decision is to let the employees process the work. However, if the supervisor had access to information, he/she would know that large amounts of inventory are already waiting to be processed by the bottleneck resource. Therefore the decision of processing the work at hand will only lead to further problems and confusion down the production line. This can lead to late deliveries, unsatisfied customers and in the most extreme case, result in a drop in future sales.

The ERP system makes all the relevant data accessible, thus e.g. it is now possible to make a decision about the processing of work at one workstation according to the situation further down the process.

5.2.3 What rules helped to accommodate the limitation?

The answer to the third question for the technology of MRP is: Before MRP was used, the rule was to do net requirements once a month.

The answer to the third question for the technology of ERP is: Before ERP, decisions were made with the data at hand which led to the development of several local optima rules, such as

1. Local efficiencies

   The policy of keeping employees busy all the time is appropriate in an environment where the status of the entire system or process is unknown. However, if it is known that the constraint is overloaded, then it will be more beneficial to let employees stop working in order to prevent aggravation of the problems at the constraint.

   In a traditional costing environment, in order to produce a least-cost unit, all production resources must maximize their output and run at maximum efficiency. However, this can lead to an increase in overtime, work-in-process, and raw material inventories. Furthermore the cycle time is lengthened (Smith, 2000:23).

2. Min-max replenishment levels for distribution

   Another example is the use of min-max replenishment levels for the reordering of materials/products. With current information systems the daily consumption data is available and can be used to control the reordering. This can be done in such a way, that no sales are lost due to out of stock situations and that high inventories do not cause limits in available working capital.

3. Product cost

   Managers allocate overhead costs to every individual product to judge whether or not the product is profitable. However, when a product is discontinued, many of the overhead costs do not simply disappear (Kendall, 2005:33). Thus the measurement of product cost can distort the decision-making process and cause products to be discontinued without having the intended effect on the bottom-line.
4. Engineering trying to complete every task on time

People are held accountable to their task estimates. This local optima measurement distorts human behaviour on projects to such an extent that project durations are often more than doubled (Kendall, 2005:33).

5.2.4 What rules should be used now?

The new rule for MRP technology is that net requirements should not only be done once a month.

The new rules for ERP technology find its origin in the direction of TOC and its holistic approach to management rather than the traditionally used functional perspective.

In order to ensure that the optimum benefit is achieved through the use of an ERP system it is essential that holistic decisions (i.e. decisions that consider all relevant data) should be made.

If the local measures are still in place after the implementation of ERP, the behaviour of the employees will not change. Therefore no real-benefit will be realised with the use of ERP. The only way to achieve full-benefit with the implementation of ERP is to change these rules to support the new era of making decisions with global data. These rules should therefore assess the global improvement caused by any decision made.

5.2.5 The current reality and future direction for ERP suppliers

Goldratt applied the "Necessary but not Sufficient" principles to the ERP environment and suggested the way that ERP suppliers and integrators should approach the implementation of this complex technology. A summary of Goldratt's findings are presented (Necessary but not Sufficient CD Series: The Role of Software):

The problem experienced by the ERP providers is portrayed in Figure 5.1. The cloud can be read as follows: The objective of the ERP providers is to maintain growth rate. In order to achieve the objective, it is necessary to capture the client environment accurately, without the need to tailor the product. This is achieved through adding more features and/or options. On the other hand, there is a need to keep the system as simple as possible in order not to complicate product maintenance, implementation and support. Thus features and/or options must be kept to a minimum.

In order to achieve the objective it is necessary to satisfy the customer's perception of value. This is achieved through implementing changes that will satisfy the customer's desires as soon as possible (Big diverse companies gain enough benefit with existing software, but changes have to be made to satisfy mid-size companies). On the other hand, there is a need to continue to be a reliable ERP supplier. This in itself a difficult task, because the software is becoming more and more complex. Therefore no changes should be implemented that will jeopardize the provider's ability to deliver.

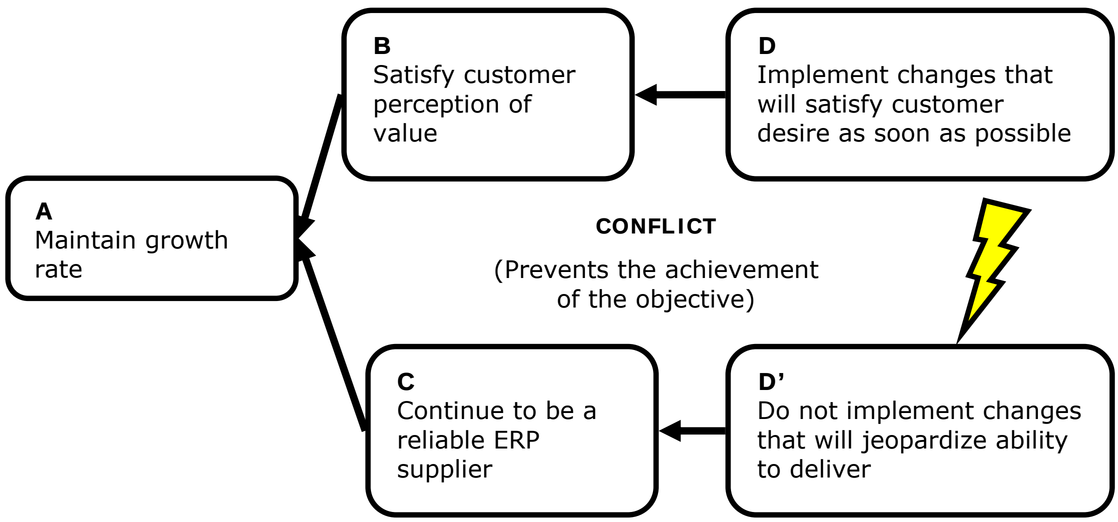

Figure 5.1: The conflict experienced by ERP providers
(Necessary but not Sufficient CD Series: The role of software. 2002)

The conflict depicted in the Figure 5.1 exists because of the following underlying assumption: The same changes that will satisfy the customer's desire will jeopardize the ERP supplier's ability to deliver.

The most important change that will satisfy the customers' desire is a positive change in their bottom line (net profit). Implementing this change does not mean that the ability to deliver will be jeopardized; the only condition is that a change in rules is also necessary. This implies that the ERP suppliers will have to change from selling software only to "value selling". This means that they must also focus on the changing of the rules of the organisation (the culture change) associated with the use of the software, in order to ensure that their customers receive the full benefit from the implementation.

Furthermore, the software used by an organisation rules the bureaucracy of the organisation. It is necessary that the bureaucracy be in line with the business rules. Therefore if the rules need to be changed, the bureaucracy must also change to facilitate the change. The software providers and integrators must collaborate to change the bureaucracy of the computer systems to fit with the new rules and bring customers fast and significant bottom line improvements.

Chapter 6:

THE APPLICATION OF THE N&S PRINCIPLES TO PRODUCT LIFECYCLE MANAGEMENT SOFTWARE IMPLEMENTATION:

This chapter begins with a discussion of the motivations for finding a new implementation methodology for PDM/PLM software. Thereafter the application of the N&S solution to the PDM software environment is presented.

6.1 THE NEED FOR A NEW IMPLEMENTATION METHODOLOGY

The rationale for an implementation, which varies between companies, provides an indicator of the type of implementation envisaged (Parr *et al*. 2000:4).

A review of marketing brochures, used in the PLM/PDM environment, and conversations with software solution providers highlighted the following: The rationale for an implementation is influenced by the selling approach used by the software solution provider. The selling approach determines the perception of the software. The perception of the software governs the determination of the implementation scope, justification and expectations/ objectives. The objectives govern the focus of the implementation and the focus of the implementation determines the implementation approach. Therefore a proper look at the current PDM implementation approaches should start at the selling approaches used to sell the software.

One way of making a software sale is to focus on the features of the software and thus a technology solution is sold. The focus is on the problems that will be solved with the software features. The sale is achieved through the admiration of the technology. The perception is that most of the benefit will be achieved by the software features itself. The scope of the implementation is therefore determined by the features that the company deems valuable and the justification follows suit. A technological implementation approach basically consists of the installation of the software and providing user training.

Garetti states that more substantially than in the past, in similar new technology implementation projects, a PLM project can be considered as a medium technology intensive project but as a high intensity project from the organisational point of view (Garetti, *et al*., 2005:47).

It is apparent that the need for organisational change with the implementation of PLM software is crucial. With technology solutions, such as PLM, evolving into tools that support and in some cases govern business strategy, the need for selling business solutions rather than selling technology has been widely recognized. Selling business solutions necessitates that during software implementations, the focus, to a greater extent, should be on changing business processes to take advantage of the capabilities of new technologies (Mines, 2005).

This need has been recognized. Business process analysis techniques have a central role in PLM projects (Garetti, et al., 2005:47).

However, believing that implementing a new information system will automatically provide the required results is still one of the common reasons for failure of PLM implementations (Stark, 2005a:53). The abovementioned reason portrays a misperception that PLM software systems are "plug-and-play" systems.

Thus even with current implementation approaches, there is still a need for an approach that can ensure that the endeavour of implementing PLM must not even be attempted without consideration of the organisational changes needed.

Generally, the extent of the organisational changes includes business process changes and some policy and procedural changes to support the new product development processes. The business process analysis and reengineering is still very much grounded in the Cost-world paradigm and the functional approach to business.

The need to optimise organisation processes rather than individual benefits poses challenging "culture change management" issues and have derailed many enterprise-scale PLM efforts (Ravi, *et al*., 2005: 227).

Holistic software requires a holistic management approach. The extent of the organisational change suggested by the N&S solution includes changes in paradigms. A new holistic management solution is proposed.

No methodology was found that explicitly introduces a change in management paradigm (in other words, change to the Throughput world paradigm) with the implementation of PLM or PDM software. Therefore the N&S solution was applied to the implementation of PDM software in order to develop a new implementation methodology.

6.2 INVESTIGATE THE NECESSITY OF PDM SOFTWARE

6.2.1. What is the power of PDM SOFTWARE?

PDM technology has been introduced in Chapter 2.

The initial idea behind PDM technology was to provide users with the required data through a single data repository, to maintain the validity and integrity of data by continual updating as well as controlling creation and modification of the data. The PDM solutions, however, expanded to include functionalities such as change management, document management, workflow management and some packages would even incorporate project management. PDM now holds the promise of enabling concurrent engineering and streamlining business processes within the enterprise (Ameri and Dutta, 2004).

PDM technology consists of two main components.

The first component addresses the enterprise information system aspect of the software: it provides a system that enables product data to be captured at the best possible source; it allows product data to be stored centrally and allows real-time data to be pushed or distributed to relevant parties (across the product lifecycle) when needed. It also allows all relevant parties to access and retrieve ('pull') the necessary product data when required. The definition of real time depends on how frequently the system changes e.g. if materials are only ordered once a month, then there is no need for hourly updates of changes. However, if materials are ordered daily then there is a need for hourly updates.

The second component addresses the automation of certain product lifecycle related processes. Automating a process involves standardizing the process; it limits the possibility of the application of the wrong process and promotes the use of the right process. Automating a process also streamlines a process by removing non-value-added activities.

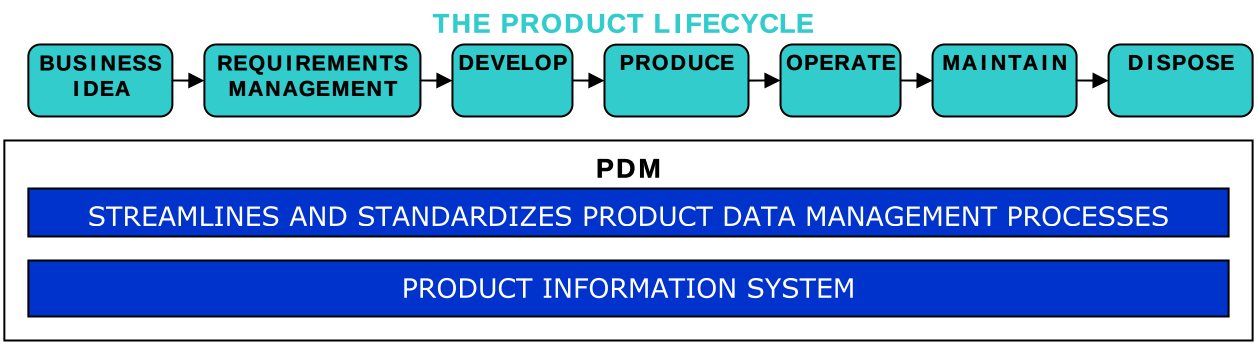

Figure 6.1: Two basic components of PDM technology

In short, the power of PDM Software is twofold (Figure 6.1):

1. It is an enterprise-wide product information system.
2. It streamlines and standardizes the product data management processes across the product lifecycle.

6.2.2 What limitations can PDM software diminish?

If the product data management environment is considered, then the following problems or undesirable effects are common (Stark, 2005b):

- Data integrity is compromised
- Increased rework
- Decreased product and service quality
- Data is not easily accessible
- Data transfers takes too long
- Necessary data is not always available when needed (specifications, information etc.)
- Increase lead times
- Collaboration with suppliers and customers is compromised.
- Internal collaboration is compromised.
- Many requirements or changes are incorporated too late in the product development process.
- Increased costs
- Increased inventory
- Increased scrap (e.g. if parts were ordered on which changes were made).
- The change process/product data processes takes too long.
- Dissatisfied customers
- Due dates are compromised.
- Uncoordinated changes to product data are made

The cause and effect relationships between these UDEs are presented as a CRT diagram (refer to Diagram 6.1). The CRT shows the effect that these problems have on company profits. The logic of the diagram is as follows:

Companies use multiple sources of product data. The use of different systems in different departments and/or the existence of personal systems for product data create a situation where data in one department is not easily available to other departments. This causes that the necessary product data is not always available when needed, which in turn hampers internal collaboration. Limited internal collaboration and the fact that necessary product data is unavailable cause many requirements or changes that are incorporated into the product development process when it is already too late. As a result there are high levels of unnecessary rework which leads to increased lead times.

If project lead times have increased significantly, it can lead to project due dates being compromised. On the other hand, if the project due date may not be compromised, then the project scope is sometimes compromised.

The multiple product data sources often contain different, and sometimes even conflicting, information about a product. As a result product data integrity is compromised. Problems with data integrity lead to differences in product specifications that exist between departments. For example, differences may exist in the product specification used by Engineering, Production and Sales. These differences result in significant amounts of rework, as well as decreased product and service quality. A more specific example is inconsistencies between CAD models, different CAD applications and BOM files that can lead to unnecessary rework in the manufacturing of the product as well as increased costs and inventory or even increased scrap (e.g. if parts were ordered on which changes were made).

Due to the multiple sources of product data, a given data element is often defined in different ways by people in different departments. Thus when the data is transferred between the different systems there is a need to reconcile the different definitions and to re-enter data. In some cases, manual re-entry is necessary. As a result, the distribution of product data is a slow and cumbersome process. This does not only lead to lengthy product data processes and compromised internal collaboration, but it can also hamper the collaboration with suppliers and customers.

Two additional factors that contribute to the problem of long product data processes are:

- The time that is used when drawings are manually transported from one activity to another.
- The chasing of signatures - certain tasks in the product development process must be signed off by different parties before the next task can start. These signatures are collected manually.

Long product data processes increase lead times. Another effect is conflicting product data e.g. a long change management process causes the use of marked-up documents and drawings that results in configuration documents that do not correspond to the actual product. This results in field service and installation teams that cannot get the correct data they should be working with. This in turn leads to unsatisfactory customer service, high service costs and inefficiencies in the spare parts management. Another result of a long, cumbersome change process is that uncoordinated changes are made, which further aggravate the data integrity problem. However, if the lengthy change process is followed, due dates can be compromised.

A compromise in project scope, project lead times, and/or product and service quality will inevitably lead to unsatisfied customers. Unsatisfied customers will result in a decrease in current and/or future sales. If sales decrease and costs increase then company profits will decrease. Profit is the measurement used to gauge the achievement of the company goal.

The logical causes for most of the common UDEs in the product data environment can be derived from the CRT diagram. It can be seen that most UDEs are caused by the use of multiple product data sources. This in turn is the cause for product data that is not easily accessible and product data that is not easily transferred or distributed. The latter effect results in product data processes that are too long and cumbersome.

In TOC the measure for achieving the company goal is an increase in company profit. The CRT shows that these core limitations hinder the achievement of the company goal and therefore, by definition, these problems can be referred to as limitations.

Thus the core limitations experienced in the product data management environment are:

- The use of multiple data sources
- Product data that is not accessible
- Product data that cannot be distributed
- Lengthy, cumbersome product data processes

The power of the PDM software is the solution of these core limitations. PDM Software provides a single product data source, manages product data access and distribution, as well as supporting streamlined standard product data processes.

As portrayed in Diagram 6.2 the single product data source ensures that valid product data is distributed and shared with all other parties involved in the product lifecycle activities. This ensures that the necessary data is available when needed, which supports internal collaboration and reduces rework.

Increased internal collaboration leads to increased product and service quality. The reduced rework and increased internal collaboration helps to decrease lead times. The fact that valid product data can be transferred in real time promotes external collaboration as well as the automation and streamlining of product data processes. This is also a contributor to the improvement in lead times. Decreased lead times results in project due dates that are more likely to be met. This ensures satisfied customers, which in turn secures an increase in sales. Combining increased sales with contained costs (due to the reduction in rework) positively impacts the company bottom-line.

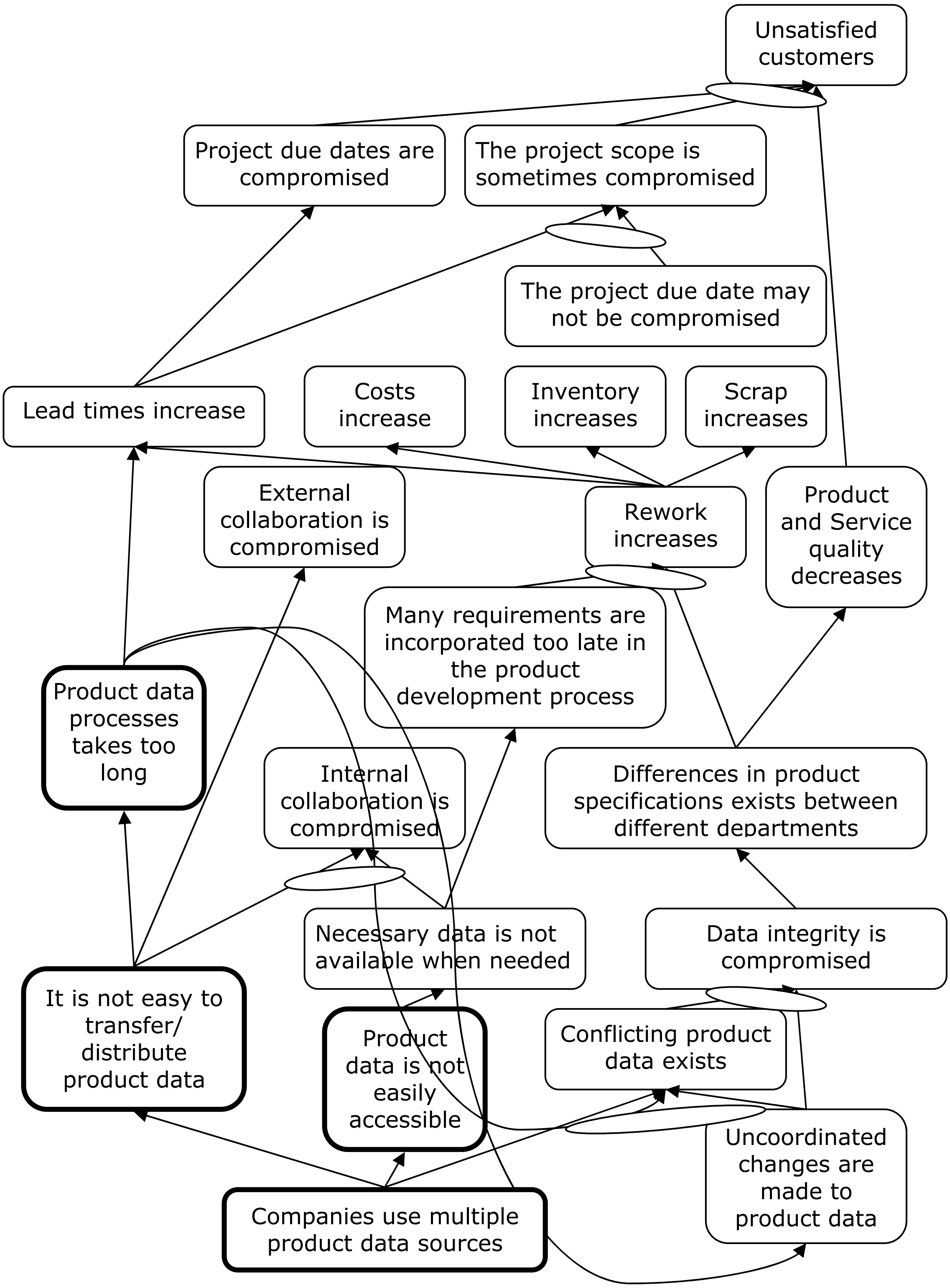

Diagram 6.1: The generic PDM CRT

The necessary conditions to achieve value with PDM software are:

- Accurate data should be in the system (because if inaccurate data is available across the product lifecycle it adds no value).
- It is essential that all relevant parties involved in the product lifecycle have access to the system (the infrastructure is necessary to ensure that the availability everywhere becomes a reality).

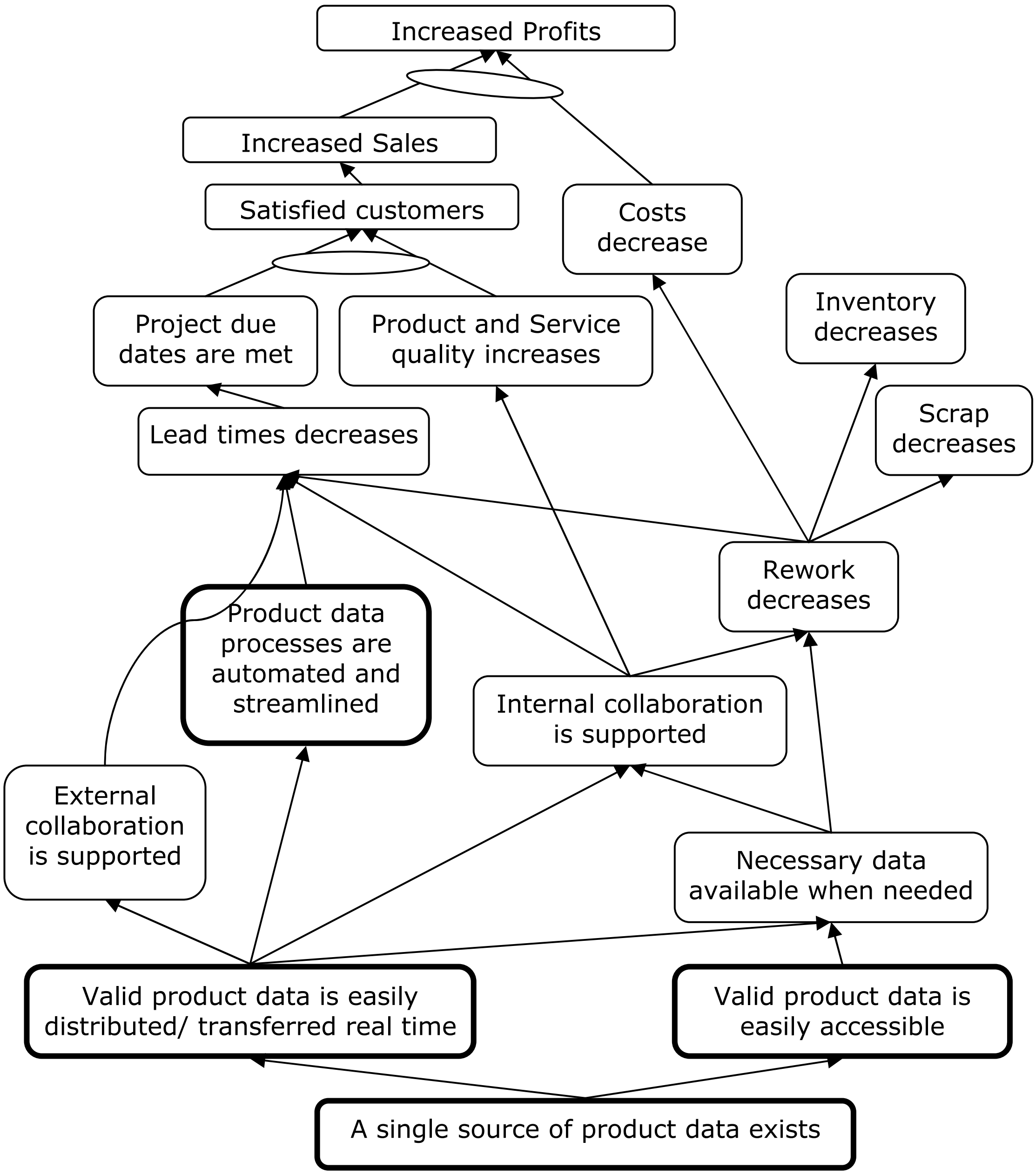

Diagram 6.2: The generic PDM FRT

6.3 INVESTIGATE THE SUFFICIENCY OF PDM SOFTWARE

"PDM cannot by itself bring about change in the product lifecycle, but it is a tool that can support the tasks in an improved process. Simply buying and installing a system isn't going to result in major benefits unless the overall environment (e.g. organisational structures, people, organisational methods, infrastructure, etc.) is supportive" (Stark, 2005a:218). The N&S Solution refers to the changing of rules.

6.3.1 The Old Rules

The old rules must first be identified. The old rules are the rules that were used to accomplish product lifecycle management without the software:

Paradigms:

Sequential engineering, also known as serial engineering, is characterised by departments supplying information to design only after a product has been designed. In serial engineering the various functions, such as design, manufacturing, and customer service are separated. The information in serial engineering flows in succession from phase to phase (Singh, 1996:104).

Without a system to control, share and distribute real-time product data, the product development environment managed the complexity of the environment by allocating different product lifecycle activities/ phases to different departments. The product development project was therefore divided into different tasks that needed to be completed sequentially. Furthermore, these tasks were managed separately.

Policies:

The formal policies used in functional/serial product development include:

- Wait for the previous task to hand over their completed work and then begin working on the next task.
- Rework is a part of the functional product development process.
- Use physical signatures to sign off product data.
- Adhere to formal product data management processes for configuration management, change management and process flow.
- Informal policies accompanies the abovementioned policy:
    - If product data is not available on time, use assumptions to make product decisions e.g. manufacturing starts producing the product before all the design specifications have been approved.

- If the formal process takes too long, certain 'short-cuts' can be used. Formal procedures will be adhered to at a later stage (e.g. rather use marked-up documents than wait for the formal change process and in some cases even make uncoordinated changes).

Measurements:

The performance of each function or lifecycle phase was measured separately according to function/phase specific criteria. Examples are given in Table 6.1 below:

LIFECYCLE PHASES	OLD MEASURES
CONCEPT	Functionality
DESIGN	Drawings/hour
ANALYSIS	Accuracy < 0.1%
PROTOTYPING	Minimum cost/prototype
MANUFACTURING	Minimum cost
	Technical excellence
DISTRIBUTION	Service levels
	Inventory turns

Table 6.1: Old measures

The consequence of these measurements can be illustrated with an example: The design office is measured according to drawings/hour. This can result in the release of drawings that do not meet all specifications in order to meet the drawings/hour target. Another example is when departments are measured by their punctuality. This results in departments delivering their work on time, but with known problems. This, in turn, results in subsequent processes having to do rework and making use of overtime in order to correct problems that could have been prevented earlier on. In a project environment, this example portrays a situation in which both the project scope and budget are compromised while striving to protect the project due date.

Behaviours:

As illustrated in the abovementioned example, the measurements cause an 'Over-the-wall' mentality. This implies that departments do what is expected of them and only focus on achieving their own performance targets, whilst disregarding the effect of their actions on subsequent processes and the product development project as a whole, which may be negatively impacted due to this kind of disregard.

Current behaviours will also include habits that have developed with the use of the previous product data management system.

6.3.2 New Rules:

The new software necessitates new rules:

Paradigms:

PDM Software is a holistic software package reaching across all product lifecycle activities. It is supported by a holistic approach to the management of the product lifecycle. This implies enabling parts of the product lifecycle to do what is good for the product lifecycle as a whole. This is supported by holistic management solutions.

PLM software is supported by collaborative product development or concurrent engineering. A survey of PDM Implementation projects in selected Swedish industries proved the importance of also utilizing the Concurrent Engineering (CE) approach in the process of implementing an enterprise-wide PDM solution. PDM systems are sometimes referred to as "CE enablers" (Sellgren *et al.*, 1996).

There exists a synergy between Product Lifecycle Management, Concurrent Engineering and holistic management principles (see Figure 6.2).

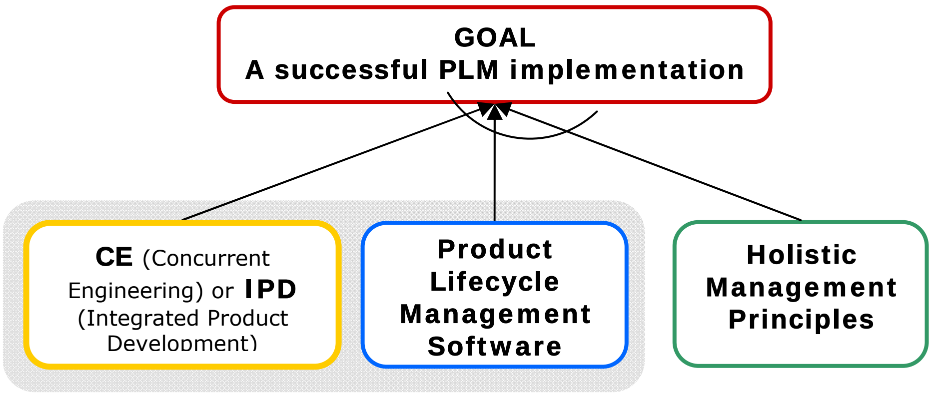

Figure 6.2: A synergy between three technologies

Policies:

Some of the necessary new policies are:

- Use the PDM system to store and manage all product data.
  The PDM system should at all times be used to manage the product data and related processes. Without the product data in the system no value can be added.
- Ensure valid data is in the system.
- Use the PDM Software and data sharing functions to communicate data.
- Wait for the data and then execute as quickly as possible.

With a system to make product data available in real time, all the non-value added activities, such as having to walk to the manufacturing department to notify them of changes, are removed from the process. Thus the waiting time for product data is reduced and should theoretically only consist of the actual time the previous task(s) are working on the product/ product data. In addition, with the holistic management work ethic (the 'relay runner' ethic) the mode of operation should be to wait for the necessary data and then to start fast execution.

- Collaborate early in the process to minimize rework.
- Only use the PDM software product data management processes
- Use digital signatures to sign off product data

Measurements:

True PDM is a very cross-functional activity, and it will not succeed without the coordinated support of all the major departments involved. If departments are only measured on their own performance then a cross-functional initiative will fail (Stark, 2005a:320).

Furthermore, a great deal of the cost of PDM originates in Engineering, (due to this department being the source of vast amounts of product data) while the benefits are found in other departments (Stark, 2005a:322). Thus without holistic measures, the benefit of the system might not be acknowledged.

There is a need for measurements that will ensure that all the parts work together towards the improvement of the performance of the product lifecycle as a whole (see Table 6.2). The direction of the solution is a combined new measurement on organisational behaviour focused on the constraint.

LIFECYCLE PHASES	NEW HOLISTIC MEASURES
CONCEPT	
DESIGN	Lead time and Buffer Management
ANALYSIS	Throughput Rand days (TRD)
PROTOTYPING	
MANUFACTURING	Throughput or
	Throughput/constraint unit
DISTRIBUTION	Throughput Rand days
	Inventory Rand days

Table 6.2: New measures

All product lifecycle phases should be measured according to holistic measures:

- An improvement in process lead time will benefit the project as a whole especially, when the specific process task is on the critical chain of a project.
- Similarly, an improvement in process throughput, such as an increase in products produced per hour, will benefit the project as a whole.
- The measurement of TRD is a measurement that starts counting when a process/task is running late (i.e. starts consuming buffers). It is assigned to the person/team responsible for the lateness and equals the Throughput (T) Figure of the project (entire project selling price) times the amount of days of buffer that has been consumed (RD). The goal is to have a zero TRD value.

Behaviours:

- Collaboration
- Doing what is good for the product lifecycle as a whole.
- New work procedures for the use of the new product data management system. This is substantiated by the following statement: "Another necessary competence is the ability to incite the involved users to a correct use of the PLM tools" (Garetti, *et al*., 2005:47).

The old rules and new rules are summarized in the Table 6.3 below:

Limitations Diminished	**What rules helped to accommodate the limitation?**	**What rules should be used now?**	**Rules Classification**
The use of multiple data sources	Use hard copies to communicate data	Use the PDM Software and data sharing functions to communicate data	Policy
	Use multiple data sources	Use the system to store all product data	Policy
Product data that is not accessible	Functional Product Development	Concurrent Engineering	Paradigm
	Locally focused management principles	Holistic management principles	Paradigm
	Local Measures	Holistic measures	Measurements
	Over the wall mentality	Collaboration	Behaviour
	Doing what is good for the function/department	Doing what is good for the project/company as a whole	Behaviour
Product data that cannot be distributed	Product decisions were made on assumptions	Withhold release of work until all data is available and when available enforce fast execution	Policy
	Wait for the data before making decisions		
Lengthy cumbersome product data processes	Short cuts can be used and then the formal procedure updated at a later stage	Only follow the PDM software managed processes	Policy
	Habits associated with the old product data management system	New work procedures that supports the new software must be implemented	Behaviour

Table 6.3: A summary of the old and new rules

As introduced earlier an organisation can be considered from both a physical point of view and a logical point of view. The rules identified thus far address the logical system view. Careful consideration must be given as to the physical structural changes (i.e. equipment, resources, structures etc.) that will have to be made in order to support the new software and the new rules.

The following physical changes should accompany the software implementation:

- The obvious structural change is the system (in other words, the hardware and software requirements of the software must be met).

- PLM and CE are supported by organisations that are horizontally integrated i.e. structured according to different product lines instead of a departmental organisational structure.

- The PDM software manages and supports engineering change management and configuration management. Traditionally, a configuration manager was responsible for the management of the configuration of a few products. With the software, one configuration manager can manage a significantly larger number of products. Thus some resources will have to be repositioned with the implementation of the software.

- Access to all relevant parties is absolutely necessary, which implies that software licences must be available to all. The value of real-time data will not be realised if the person responsible for a task can only access the product data periodically due to e.g. the sharing of access points or limited availability of software licenses.

6.4 EXPECTED RESULTS

The implementation of these new rules during the implementation of the PDM Software will result in bottom-line benefit. The cause and effect logic to substantiate this claim follows (refer Diagram 6.3):

The PDM software system can provide a source for all product data. However, if rules are not implemented to prevent the use of personal systems, the software cannot bring benefit. It is essential to formulate rules to promote the use of the PDM software as the single repository in which to store and manage product data.

The PDM software provides easy access to product data, which results in necessary data that is available when needed. If this is combined with a relay runner ethic, lead times and rework can be reduced.

The software supports internal (and external) collaboration, but only with the implementation of a new CE and holistic paradigm, can the benefits of the collaboration be achieved.

The PDM software provides streamlined standard product data processes, but the benefits can only be realised if the new software-based processes and procedures are enforced.

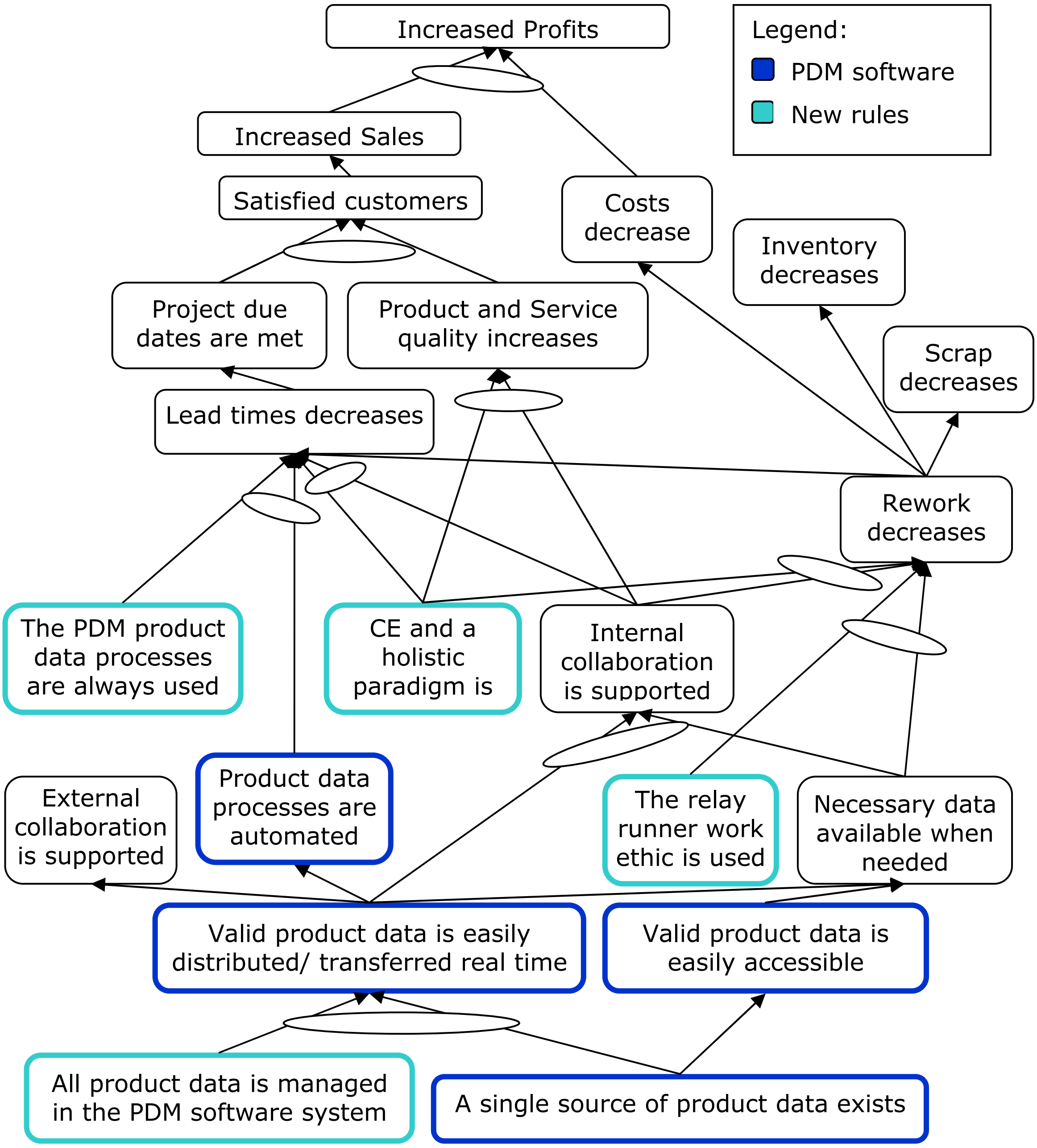

Diagram 6.3: FRT with new rules injections

Chapter 7:

PRODUCT DATA MANAGEMENT SOFTWARE IMPLEMENTATION METHODOLOGY

The application of the N&S principles to PDM Software was used as the basis for the development of an implementation methodology that will ensure realisation of full benefit.

From a TOC perspective, significant benefit will only be achieved if the constraint of a system is identified and managed or improved. Thus the framework for the implementation methodology is the five focusing steps (refer to Chapter 4). The TOC analysis tools introduced in Chapter 4 is employed in the implementation methodology.

7.1 GENERIC IMPLEMENTATION METHODOLOGY

STEP 1: DEFINE THE SYSTEM TO BE IMPROVED

The implementation of new software is usually done as part of an improvement initiative. One of the prerequisites for any improvement process is to define the system and its purpose (Scheinkopf, L. 1999: pp. 23-24). Therefore this will be the first step of the implementation methodology.

Software is usually acquired in order to improve the performance of a department/function. Improvement of departments/functions is done with the ultimate objective of improving the organisation as a whole. This is measured by the impact on company bottom-line/profit. If an improvement in a department does not lead to an improvement for the organisation as a whole, the improvement initiative is questioned.

<u>Outcomes:</u>

- The system is identified
- The system goal is defined
- The measurement for success is defined.

<u>Process steps and application</u>

1.1 Define the system to be improved.

The system to be improved can be the company or a department / function.

1.2 Define/verbalize the goal of the identified system

If the system to be improved is the company, then the goal of making money now and in the (i.e. increasing profit) applies. Thus this step consists of verifying the ultimate goal of making money now and in the future with stakeholders.

The system can, however, also be a department or function:

- If the function/department is the internal constraint, the goal will be to maximize the T through the constraint.
- If the function/department is not the constraint then the goal will be to enhance subordination to the constraint. This is done by adding protective capacity.

  An example of increasing protective capacity: The constraint is in production. The function responsible for the Engineering change process is removed from the constraint. This function decides to improve their engineering change process time from eight hours to one hour by adding more resources (people and/or software). The result is an increase in the T of the constraint due to the significant decrease in the time that production waits for engineering changes to be processed. Such a decision is only justified if the increase in T through the constraint is more than the increase in OE due to the added resources.

1.3 Determine what must be measured to show achievement of the goal.

Any local improvement should be aligned to achieve the goal of increased profits. An increase in company profits can in turn be achieved through an increase in T and/or a decrease in OE.

STEP 2: IDENTIFY THE SYSTEM'S CONSTRAINT

TOC is based on the premise that the constraint of a system is the leverage point that will ensure significant improvement of the system. Thus the second step is to identify the system's constraint. Physical and logical leverage points exist.

<u>Outcomes:</u>

- The system logical leverage point (i.e. the core problem) is identified and verbalized
- The system physical constraint is identified

Process steps and application:

2.1 Identify/verbalize the core problem:

Research will have to be done to determine the available TOC solutions. This step then consists of verifying if the UDEs identified as a part of a TOC solution exist in the company's current reality. If the UDEs are significant then the existence of the applicable core problem should be verified.

2.2 Identify the system physical constraint:

If the UDEs and the identified core problem was verified, then implementing the applicable TOC solution will unlock significant hidden capacity which can imply that the system constraint is actually in the market. Thus the current mode of managing is blocking the ability to capitalize on the potential available capacity.

If this is not the case, then the system physical constraint can be found by using the following logic:

Find out whether the raw materials used are very scarce. If this is the case, verify that raw material supply limits the throughput of the system. If this can be verified, then the physical constraint is the raw material supply.

If the raw material supply is not the constraint then find out whether cash flow limits the throughput of the system. If this is the case then the system constraint is the cash flow of the business.

If, however, this is not true then verify if an internal constraint exists. An internal constraint is also known as a bottleneck and usually refers to a production bottleneck, although a department or function can also be the internal constraint.

A production bottleneck will become evident by working with expediters, schedulers and managers. The following questions can help with the identification of the bottleneck:

- Where is the most constrained resource – the bottleneck?
- What resource, more than any other, governs the throughput of the entire operation?
- Where is most work-in-process waiting to be processed?
- Where do the expediters go to find a late order?

If product development limits the flow of work through the organisation then it is the bottleneck. This can be recognized if production frequently waits for the product development department, whether it is for some changes to be made to existing products or for new products to be released.

A wandering bottleneck is usually caused by policies and is a sign of substantial excess capacity. By managing the system in a different way (i.e. changing current policies) it is possible to unlock hidden capacity and to eliminate all internal constraints.

A market constraint exists if the company can offer more than what their current market demands.

STEP 3: DECIDE HOW TO EXPLOIT THE CONSTRAINT

The physical constraint governs the throughput of the system. Thus the throughput of the system increases when the ability of the constraint to produce is increased.

Factors exist in the current reality of the company that block the constraint from achieving its full potential. These factors can be described as undesirable effects (UDEs). An exploitation decision involves deciding what changes are necessary in order to remove the blocking factors. These changes can either involve changing the way the system is managed and/ or implementing new technologies.

If a core problem that a specific TOC solution addresses is applicable to the environment, then the first source of exploitation decisions will consist of implementing the TOC solution i.e. changing the way the system is managed. If none of the core problems are applicable then the first choice for exploitation decisions will most likely be the implementation of new software. Exploitation decisions can consist both of changing the way the system is managed and implementing new software. PDM software implemented in the context of PLM is supported by holistic management principles, therefore in most cases a synergy will be seen between the implementation of the TOC solution and the PDM software.

The N&S solution highlights the establishment of the necessity of the implementation of new technology. Thus a decision to implement PDM software as a part of the exploitation of a constraint can only be made once the necessity of the software has been proven i.e. it must be proven that the PDM software diminishes limitations or blocking factors.

The process followed to achieve this is to identify the UDEs that exist in the current reality of the company and then to map the CRT. Then those UDEs that are core limitations can be identified. If the power of PDM software addresses the core limitations, then the PDM software is necessary.

If PDM software does not address the core causes, then either the way that the system is managed should be changed or else a different technology will address the core limitations and should therefore be considered.

Outcomes:

- A list of UDEs
- The CRT diagram/UDE map
- A list of the UDEs that are core limitations
- The necessity of the software is justified
- The ROI justification for the software

Process steps and application:

3.1 Identify the blocking factors

3.1.1 Identify UDEs

An approach used to identify UDEs is to ask employees from different departments in the organisation to identify an existing troubling issue from their area of responsibility. This issue is an undesirable effect if verbalized correctly (refer to Chapter 4).

3.1.2 Build the CRT/UDE map

The cause and effect relationship between all the UDEs must then be established. This can be done by considering two UDEs and establishing if the one might be the cause of the other. If no relationship exists between the two UDEs then consider a third UDE and again establish if it might be the cause or the effect of one of the other UDEs. This process should be followed until the links between all the UDEs have been defined. The CRT diagram format must be used to portray the links between the different UDEs (refer to Chapter 4).

3.2 Investigate the necessity of the software

3.2.1 List the UDEs that are core limitations

The core limitations are those few UDEs that cause the existence of the other UDEs.

3.2.2 Show that the software will address the UDEs that are core limitations

This step consists of investigating if the PDM software with its specific power (the power of PDM software is given in Chapter 6) can diminish the core limitations experienced in the current reality of the company.

3.3 Complete the ROI justification for the software

3.3.1 Determine the significance of the UDEs

The benefit of removing the limitations/blocking factors must be quantified. In TOC practice, the gap between potential Throughput (T) and current T is quantified and then a percentage of the gap is allocated to each blocking factor. The percentage represents the contribution to the existing gap that is made by the blocking factors or in other words the percentage represents the improvement in T that will result when the blocking factor is removed. This is done to validate the significance of the identified blocking factors and also makes it possible to rank the different factors. In Figure 7.1 it can be seen that if UDE 1 is removed it will result in a 20% improvement in performance and the removal of UDE 2 will result in a 10% improvement in performance. TOC accepts that a certain percentage of the gap in performance is due to reasons that are not within the control of the person responsible for the system (labelled in the diagram as "Murphy").

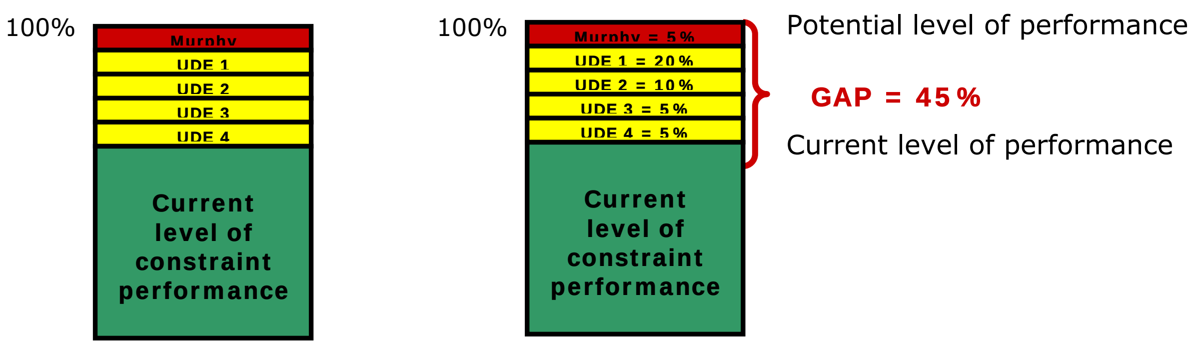

Figure 7.1: Exploitation Diagram and Defining the GAP

In most cases the gap will be made up of the UDEs addressed by the software as well as other UDEs. If the limitations that are diminished by the technology only represent an insignificant portion of the defined gap then warning lights should go on as to the ability of the software to add value.

3.3.2 Do the ROI calculation

The ROI calculation can then be done according to the improvement in T that will materialize when the limitations are diminished, as well as the change in investment and operating expense that will occur with the implementation. A positive ROI is an indication that the implementation of the technology will achieve bottom-line benefit. The formula used is ROI = (T-OE) / I (refer to Chapter 4).

STEP 4: SUBORDINATE TO THE EXPLOITATION DECISIONS

The hidden capacity can only become added capacity through the realisation of the exploitation decisions. This, in turn, involves the subordination of the system to the constraint. Subordination is realised through implementing the new constraint aligned rules and metrics.

The final solution can therefore consist of the implementation of a TOC solution to address the core problem and/or the implementation of the PDM software. New constraint aligned rules and metrics must be developed and implemented with the implementation of the new software in order to achieve benefit. The solution can be portrayed as a future reality tree (FRT) that contains the solution components and how it causes the desired effects that will help to ensure a better achievement of the system goal. The last step is the development of transition/ action plans to transform the current reality into the desired future reality.

<u>Outcomes:</u>

- A list of old rules
- A list of new rules
- FRT
- Transition plans

<u>Process steps and application:</u>

4.1 Investigate the sufficiency of the new technology

4.1.1 Identify the rules used to accommodate the limitation(s).

This step consists of listing current paradigms, policies, measures and behaviours. Chapter 6 presents the synergy between PLM, CE and holistic management principles and proposes these three paradigms as a necessity for the implementation of PDM software within the context of PLM. Thus the existence of these paradigms in the current reality should be verified.

If a core problem was applicable to the current environment then another source of current rules will be the policies and measures that contribute to the existence of the core problem.

If the organisation is structured according to departments than departmental policies and measures should be documented. These policies and measures must be analysed and challenged in order to reveal imbedded inherent conflicts that might inhibit collaboration or any of the other paradigms.

Lastly the current product data management system approaches, procedures and habits must be documented.

4.1.2 Identify the rules that should be used now.

The sources for new rules can be:

- The rules associated with the TOC solution that addresses the identified core problem.
- The constraint-aligned new rules that should be implemented with the PDM software.

An approach that can be followed is to identify the desired effects (as opposed to the current undesirable effects).Then the changes in paradigms, policies, measures and behaviours that are necessary to ensure that the desired effect becomes a reality must be identified.

The new proposed paradigms, PLM, CE and holistic management principles, are the foundation for the development of the new rules.

The implementation of holistic management principles is done through the implementation of holistic policies and measures. TOC is a holistic management philosophy and TOC literature can be used as a guide to develop new holistic policies. The holistic measures to be used in a product development environment are proposed in Chapter 6. In addition to this, rules will have to be developed to support the CE approach.

If the PDM software applies certain preferred models or approaches, then these approaches should be taken into consideration with the development of the new PDM software specific works procedures. For example PTC’s PDMLink software applies the

CMII approach to configuration management. Therefore the rules for configuration management should support the CMII approach.

The capabilities and best practices proposed by the software developer is a definite source of new rules. The architecture or build of the software might even necessitate specific work procedures which should be taken into account with the development of the new rules.

The holistic measures are listed in Chapter 6 and should be applied in order to support a holistic product lifecycle approach.

The behaviours that are necessary to support the implementation of PDM software is that of collaboration, doing what is good for the product lifecycle/company as a whole and actually applying the new software specific work procedures. Thus the listed new rules can be validated by checking if it will cause the wanted behaviours.

Careful consideration must also be given to the necessity of changing physical system structures such as e.g. changing the organisational structure or IT system hardware.

4.2 Develop the final solution

The desired effects and changes in rules are the building blocks used to develop a complete FRT diagram (refer to Chapter 4). The cause and effect links between the different building blocks must be established by using a similar process to the one followed to determine the cause and effect links between the UDEs for the development of the CRT/UDE map.

4.3 Develop transition plans (from CRT to FRT)

This step consists of the development of action plans that will help take the company from the current reality to the desired future reality. The process followed commences with the development of a prerequisite tree to create an implementation roadmap. The injections of the FRT are the objectives of the prerequisite tree. The intermediate objectives and injections defined on the prerequisite tree are then used as the objectives for the transition plans (refer to Chapter 4).

STEP 5: IMPLEMENT, MONITOR AND TAKE ACTION

This step includes the development of training material for the implementation of the software. The software user training should be customized to include training in the specific new works procedures to be implemented with the software.

Most importantly this step involves the monitoring of the company constraint. If the constraint moves then actions must be taken to re-align the rules, that were developed for the implementation of the software, to the new constraint.

The progress regarding the use of the software, the accompanying new processes and procedures, as well as the new rules should be monitored closely for a start-up period in order to ensure that the new concepts are understood, accepted and applied. Actions must be taken if the implementation is not going according to plan.

A detailed roadmap is presented in Figure 7.2.

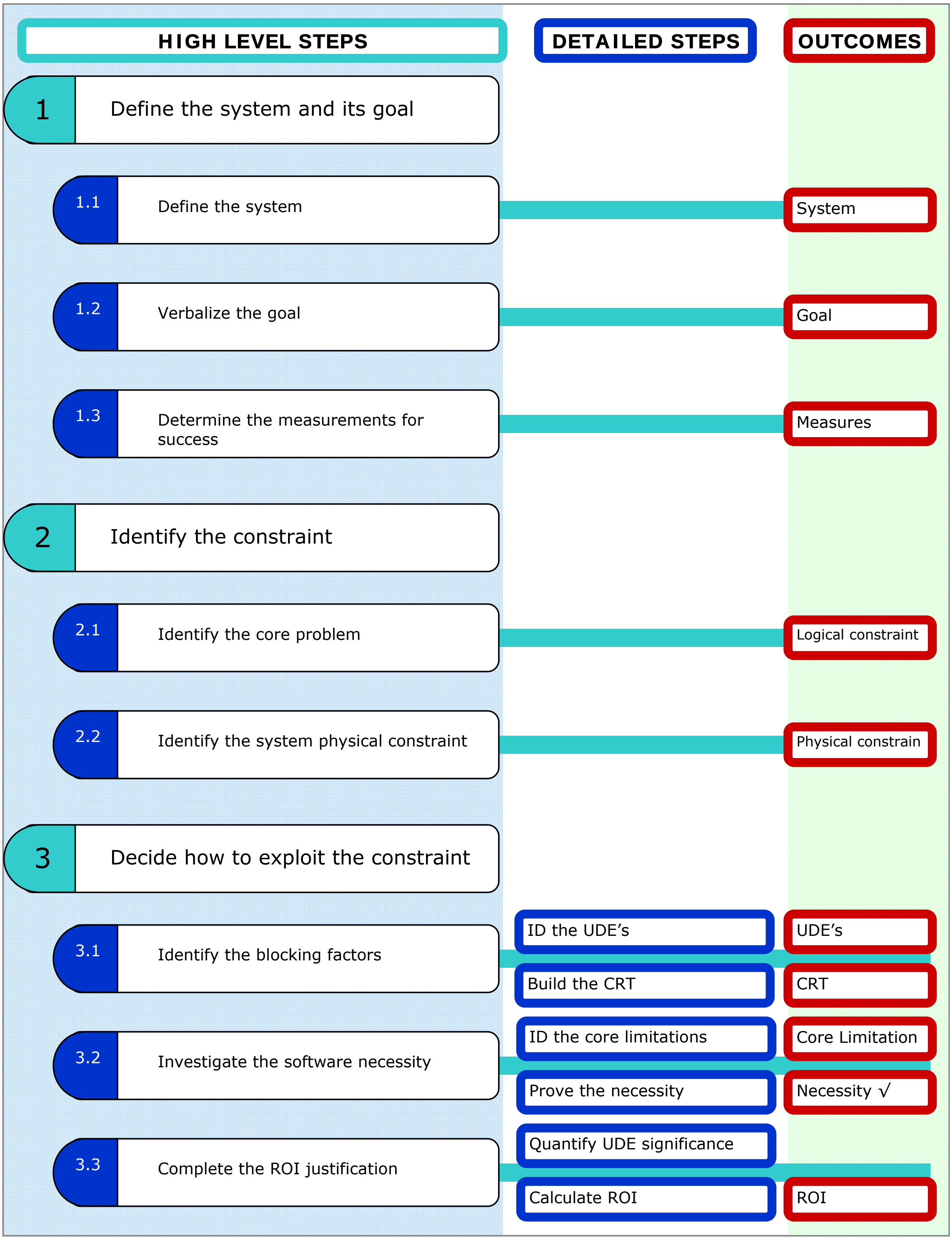

Figure 7.2: Detailed Implementation methodology roadmap

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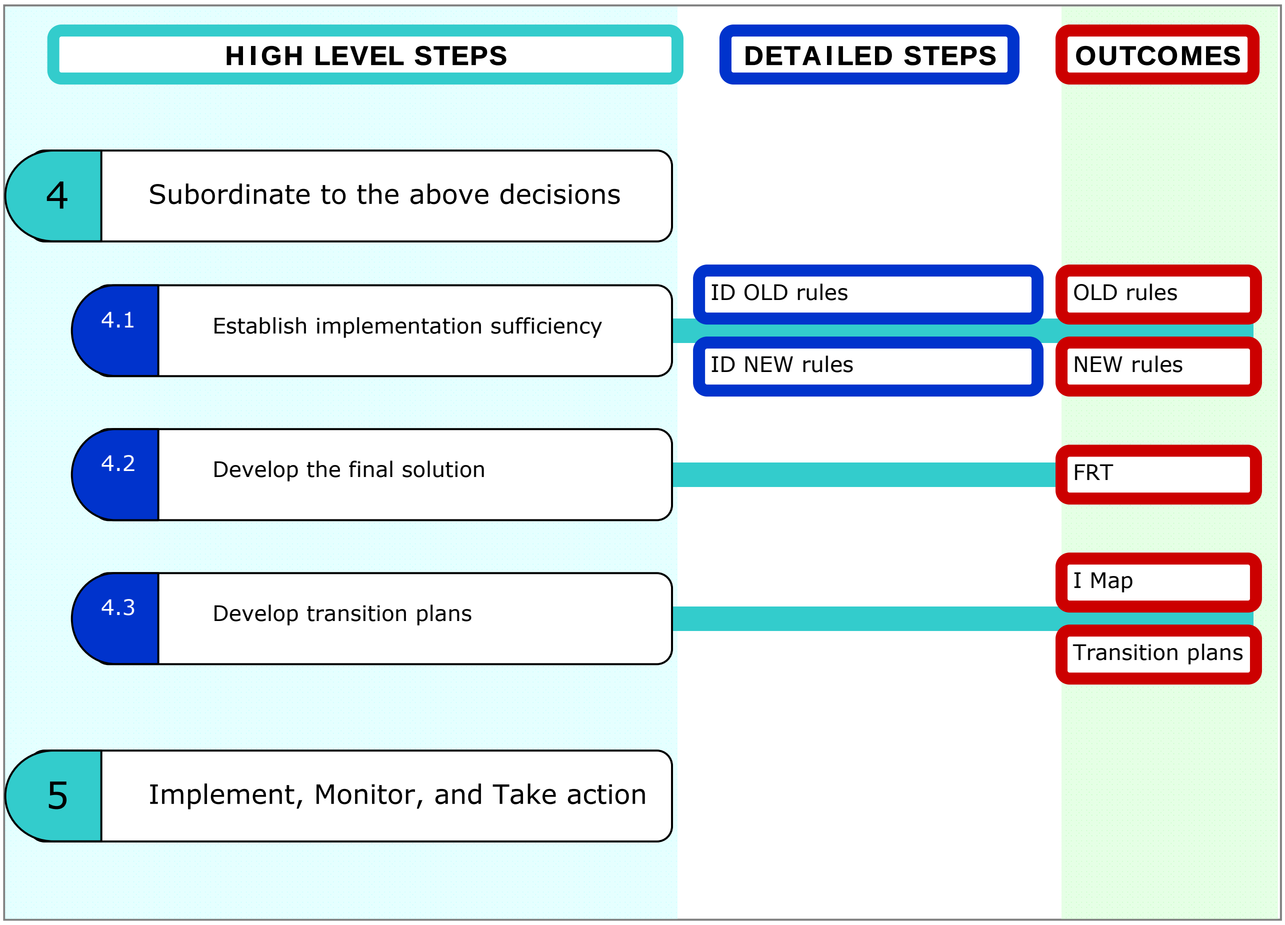


Figure 7.2: Detailed implementation methodology roadmap

7.2 ENSURING TOP MANAGEMENT BUY-IN

It is essential that top management is involved in the implementation effort. The findings up until the development of the final solution should be presented to the executive management team before the transition plans are developed. TOC has developed a process for achieving buy-in. The executive presentation will follow the structure of the buy-in process:

1. Establish the agreement on the problem:
   The first step is to validate the findings in terms of the identification of the constraint and the blocking factors. The current reality tree should be validated.
2. Establish agreement on the direction of the solution:
   The direction of the solution to the problem is the introduction of the new technology as well as the introduction of the need to change the rules. Thus the N&S solution frame of reference should be established.
3. Agree that the solution will yield the desired effects
   Thereafter the necessity and sufficiency of the technology implementation must be validated.

4. Identify negative effects

   The high level negative effects associated with the final solution must be identified and resolved.

5. Identify the implementation obstacles

   The obstacles to the implementation of the final solution must be identified and resolved.

6. Get the go ahead to develop the detailed implementation plans.

   The last step is an agreement that the detailed implementation plans (i.e. the transition plans) may be developed and implemented.

Chapter 8:

CASE STUDY - THE PRACTICAL APPLICATION OF THE PDM SOFTWARE IMPLEMENTATION METHODOLOGY

The PDM implementation methodology was applied to a case study. The case study is an implementation of PDM software that is already in progress and is experiencing difficulties. The methodology was applied to this case, firstly in order to verify the methodology approach to a PDM software implementation and secondly to identify areas to improve or change the implementation approach in order to ensure that benefit will be achieved with this specific implementation.

8.1 BACKGROUND INFORMATION

The company implementing the PDM software is Denel Aerospace Systems (DAS). The implementation partner is Automated Reasoning, a leading Engineering and Manufacturing software solution provider. The PDM software that is being implemented is PTC's Windchill PDMLink software package.

DAS specialises in the design, development and production of the following products:
Guided Weapon Systems, Unmanned Aerial Vehicle Systems, Attack Helicopters and Air Defence Systems.

Products are managed as programs. The final deliverable is the functional hardware and in some cases the delivery of support services.

The following departments are involved in the product lifecycle:

- Program managers
- Engineering Department
- Engineering Services department consists of several units: Mechanical Design Office (which includes a sub function: Checking), Printed Circuit Board Design Office, Configuration Management, Document Control Centre, Publications and Graphic Design, and Codification).
- Industrialisation department
- Production department
- Support Engineering department

The roles of the departments in the product lifecycle are as follows (see Figure 8.1):

The program managers have to manage the program which involves the development of a complex product. Due to the complexity, the development of the product is managed as several smaller projects. The program managers together with the engineers develop different concepts. After a concept has been approved the engineers start with the design. The engineering services department does the 3D modelling of the product designed by the engineers. From the 3D model engineering drawings are generated. The checked drawings are made available to the production department to start the manufacturing of the product. After development has been completed, the industrialization department makes changes in order to make the product easier to manufacture. The support engineering department is involved in identifying client needs, ensuring a supportable product is designed and provides support to clients.

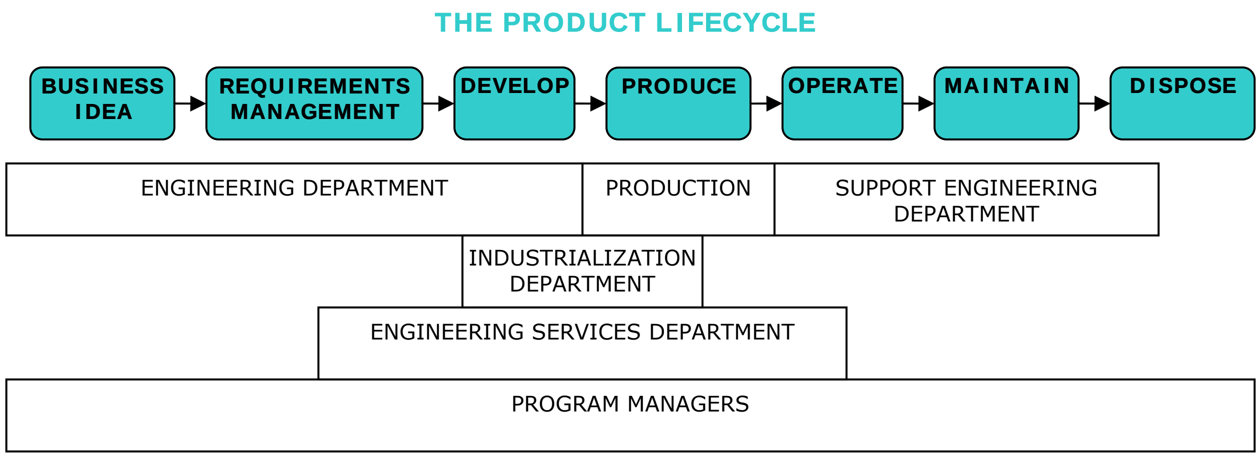


Figure 8.1: The DAS departments involved in the product lifecycle

8.2 ANALYSIS

The existing implementation was analysed using the implementation methodology framework.

1. DEFINE THE SYSTEM TO BE IMPROVED:

1.1 Define the system to be improved:
The software was acquired to improve the performance of the Engineering Services Department.

1.2 Define/verbalize the goal of the identified system:
The goal of the Engineering Services department is: To create, collaborate and control data and documentation rapidly, in order to meet contractual requirements *(Source: Interview)*. The goal of the implementation of PDMLink was to help the Engineering Services Department to better achieve this goal by providing the adequate infrastructure.

1.3 Determine what must be measured to show achievement of the goal:
In the current implementation no measurement was identified or defined (the need for one, however, was recognized).

2. IDENTIFY THE CONSTRAINT:

2.1 Identify/verbalize the system logical constraint

The traditional way of managing projects and the accompanying undesirable effects are apparent in the current reality of DAS. The common project management UDEs that are experienced in the current reality of DAS are:

- Often the priorities of tasks change
- Resources are not always available when needed
- Often tasks take longer than expected
- Often promised due dates are not met
- There are budget overruns
- A large amount of rework is done

These UDEs are the symptoms of the project management core problem presented in Figure 4.4. This core problem is experienced in most project management environments today. It is caused by the common belief that the only way to ensure that the project will finish on time, is to try to make every task finish on time.

2.2 Identify the system physical constraint

The Critical Chain Project Management solution was designed to address the above-mentioned core problem. TOC claims that significant hidden capacity will be unveiled if Critical Chain Project Management principles are implemented into DAS (refer to Chapter 4). From a TOC perspective DAS has a significant amount of hidden excess capacity (Goldratt Group, 2002). The company constraint is therefore in the market.

3. DECIDE HOW TO EXPLOIT THE CONSTRAINT

Exploitation of the market constraint can be achieved by e.g. developing a competitive advantage by improving logistical performance to give shorter lead time, higher due date performance, offering penalties, etc. Thereby it is possible to provide new offers to the market that are so good that they cannot be refused.

Currently DAS is however in a situation where they are struggling to meet commitments made to customers. A logical analysis was done to identify what is blocking DAS from achieving at least the goal of meeting original commitments to clients. The ability to meet original commitments will positively impact the company bottom-line.

3.1 Identify the problem (blocking factors):

3.1.1 Identify UDEs

The data gathering was done in the form of interviews (refer Appendix 2: DAS Interviews) in which the concerns, issues and problems experienced by the interviewee in everyday operations were addressed. Interviews were held with management Figures of most of the departments that are involved in the product lifecycle activities. The outcomes of the interviews were the identification of the undesirable effects (UDEs) that are present in the current reality at DAS.

The following UDEs were identified from the interviews held with the different departments within the Engineering Services Department:

- Resources are not always available when needed
- 30% of the Design office's time is used for administrative tasks (chasing signatures; SAP upload; PDF documents)
- A significant amount of rework is done
- Necessary things are not available on time (information, specifications, designs, etc.)
- Configuration management is not done according to a standard process
- Often tasks take longer than expected
- Often the priorities of tasks change
- There are budget over-runs
- The system cannot accommodate 'simple' change requests
- Too often promised due dates are not met
- Legacy data takes too long to retrieve

In addition, interviews with other departments revealed the following UDEs:

- Some requirements/changes are incorporated too late (after the release of the Bill Of Materials (BOM) in the product development process)
- Some product data is stored in isolated databases
- The quality of data is inconsistent
- The project scope is compromised
- It is difficult to satisfy client requirements
- The Engineering Change Proposal (ECP) lead time is too long
- Raw materials/parts are not always available when needed
- All product data is not thoroughly documented
- Sub-standard raw material components are sometimes purchased
- Procurement takes too long
- Too many changes take place

3.1.2 Build the CRT/UDE map

The cause and effect relationship between the different UDEs mentioned in the previous subsection follow. Their relationships are portrayed in an UDE map (refer to diagram 8.1 below).

Due to the fact that no system currently exists in DAS for sharing real time product data with all parties involved in the product lifecycle, the quality of product data used is inconsistent and some requirements or changes are incorporated too late in the product development process.

The inconsistency in the quality of product data combined with the fact that some requirements or changes are incorporated too late in the product development process cause many changes that have to be made to the product and/or product data.

The increase in the lead time of Engineering Change Proposals (ECP), the formal change request procedure, is caused due to an increase in change requests combined with the fact that there is no system to accommodate and speed-up simple change requests (all change requests have to go through the long formal process).

The long ECP lead time causes that necessary aspects, such as information, specifications and designs, are not available when needed. This in turn causes that uncoordinated product changes and product decisions are made. These uncoordinated changes are the main cause of the configuration documents not corresponding to the actual product.

An increase in changes inevitably leads to an increase in rework. In addition, the uncoordinated changes and configuration documents that are not up-to-date also increase rework.

The fact that 30% of the Design office’s time is spent on administrative tasks, combined with the ever increasing rework, results in resources that are not always available when needed. This in turn necessitates funds to be spent on more resources which contribute to frequent budget overruns. Furthermore, the fact that some requirements and changes are incorporated into the product development process too late, leads to extra expenses in order to get additional or different parts and/or materials. This in turn contributes to the following: (1) budget overruns and (2) an increase in inventory and/or obsolete parts. Budget overruns leads to an increase in costs.

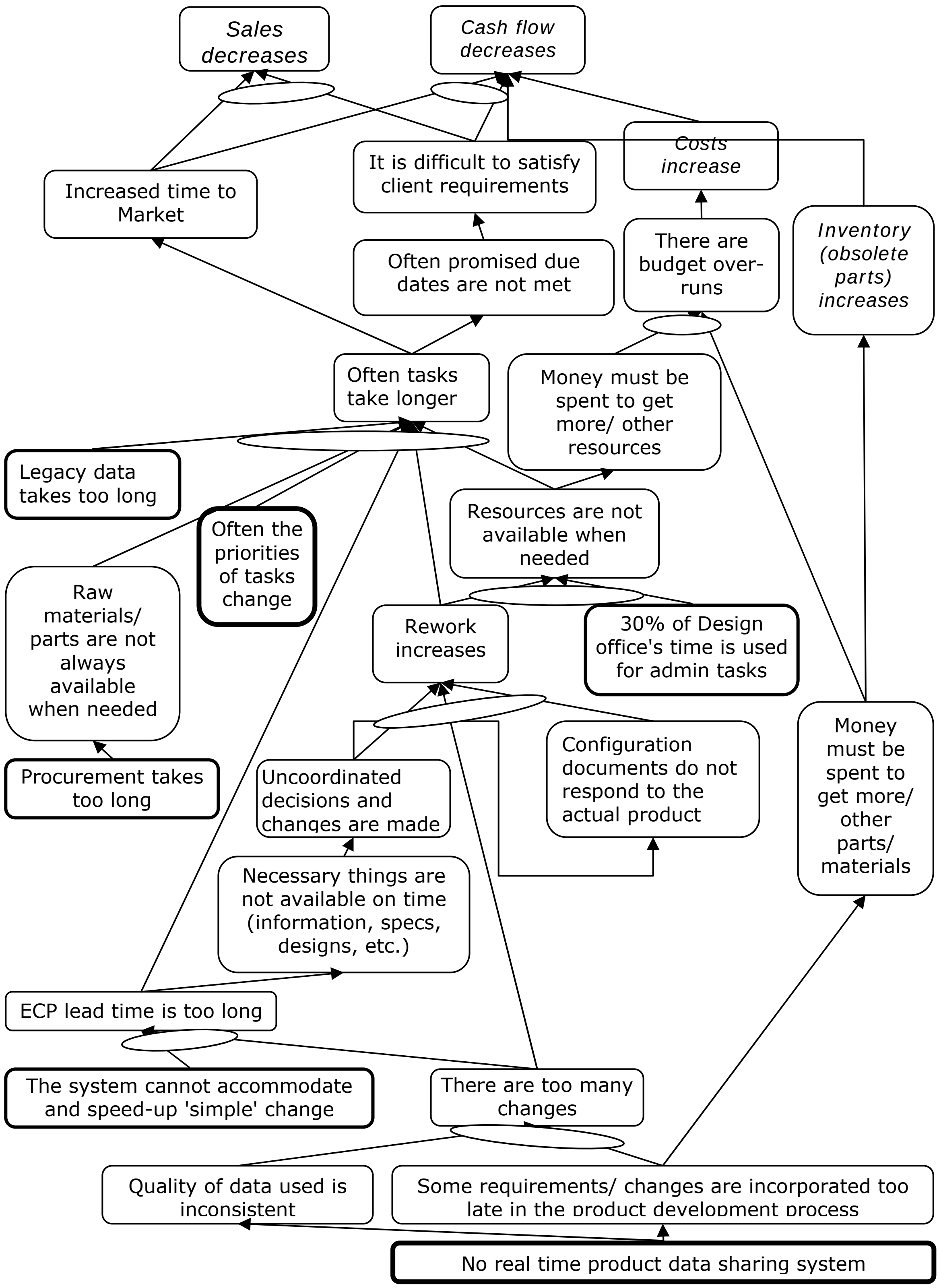


Diagram 8.1: DAS CRT

The following factors contribute to the growing reality of tasks that often take longer than expected: (1) increasing rework, (2) long ECP lead times, (3) resources that are not always available when needed, (4) legacy data that takes too long to be retrieved (since it is stored in a container on site), and (5) priorities of tasks that often change. In addition, the long lead time of procurement causes the unavailability of raw materials, which aggravates the problem of tasks that take too long.

The inevitable result of tasks that take longer than expected is promised due dates that are not met, as well as an increase in time to market. This in turn results in unsatisfied customers. The final outcome is a decrease in cash flow and sales.

3.2 Identify the direction of the solution:

Aligned with the N&S solution only the software/ new technology that addresses the core problems will add value and therefore be necessary.

3.2.1 List the UDEs that are core limitations

From the CRT diagram (Diagram 8.1) the core limitations can be identified as:

- No real time product data sharing system exists
- Currently ‘simple’ change requests cannot be accommodated
- 30% of the Design office's time is used for administrative tasks
- Legacy data takes too long to retrieve
- Often the priorities of tasks change
- Procurement takes too long

3.2.2. Investigating the necessity of the PDMLink software

Most of the core undesirable effects are directly addressed by the power and capabilities of the PDMLink software, therefore the technology is necessary (Table 8.1).

3.3 Complete the ROI justification for the software

The quantification of the impact of the limitations was not done and no ROI calculation was done. The number of times that the same limitation came up in the interviews across the product lifecycle was used as an indication of the significance of the limitations and its effects. The assumption made is that the removal of these limitations will contribute significantly to the improvement of overall company T.

UDEs	**PDM Software: POWER**	**PDMLink Capabilities**
No real time product data sharing system exists	It is an enterprise-wide product information system	PDMLink provides a data source for all product data generated and used across the entire product lifecycle.
Currently 'simple' change requests cannot be accommodated	It streamlines and standardizes the product data management processes across the product lifecycle.	The PDMlink system automates the change management process and it has a capability to distinguish between full track or fast track changes.
30% of the design office's time is used for admin tasks	It streamlines and standardizes the product data management processes across the product lifecycle.	The chasing of signatures, saving PDF-files and uploading work into the ERP system takes a long time to do. PDMLink has the ability to publish documents in a PDF format at check in, the automation of business processes will address the chasing of signatures, and the ability to seamlessly support ERP production business processes with bi-directional information exchange will remove the problem of uploading data to the ERP system.
Legacy data takes too long	It streamlines and standardizes the product data management processes across the product lifecycle.	A library system enables access to legacy data from the personal desktops.

Table 8.1: The core limitations addressed by PDMLink

4. SUBORDINATE TO THE EXPLOITATION DECISIONS

The PDMLink software can contribute to the improvement of the system but as the N&S solution identifies rules will have to be changed. Thus the sufficiency of the implementation must be checked.

4.1 Investigating the sufficiency of the PDMLink software

4.1.1 Identifying the rules used to accommodate the limitation(s)

Current Paradigms:

Currently the product development in DAS is still very much divided into functional tasks, eventhough the need for concurrent engineering has been recognized.

Critical chain project management principles have been introduced to DAS, but the existence of the UDEs shows that this project planning discipline is not rigorously applied. The project management paradigm applied is still very much focused on managing project tasks.

The project management core problem applies to DAS's current reality. DAS is currently dealing with this core problem by making compromises in project budget and due date performance in order to always protect the project scope. Diagram 8.2 portrays the dilemma (an A3 sized diagram is included in Appendix 4: The core conflict of DAS).

This drive to protect the project scope is the cause for:

- The increase in changes and rework
- The fact that uncoordinated changes and decisions about a product are sometimes made.
- Configuration documents do not correspond with the actual product.
- Requirements and changes are incorporated very late in the product development process
- Funds are spent on getting more/other materials and/or parts
- Funds are spent on more/other resources

The outcomes of all these actions are a decrease in sales that compels DAS to take actions to compensate for early mis-estimations / mis-considerations. On the other hand, the actions lead to increasing costs and inventory which requires DAS not to compensate for early mis-estimations / mis-considerations. Therefore, even with the current focus of always protecting project scope, the core conflict still exists.

Without addressing this core problem with the development of the new rules, significant improvement will not become a reality and the downward spiral will continue.

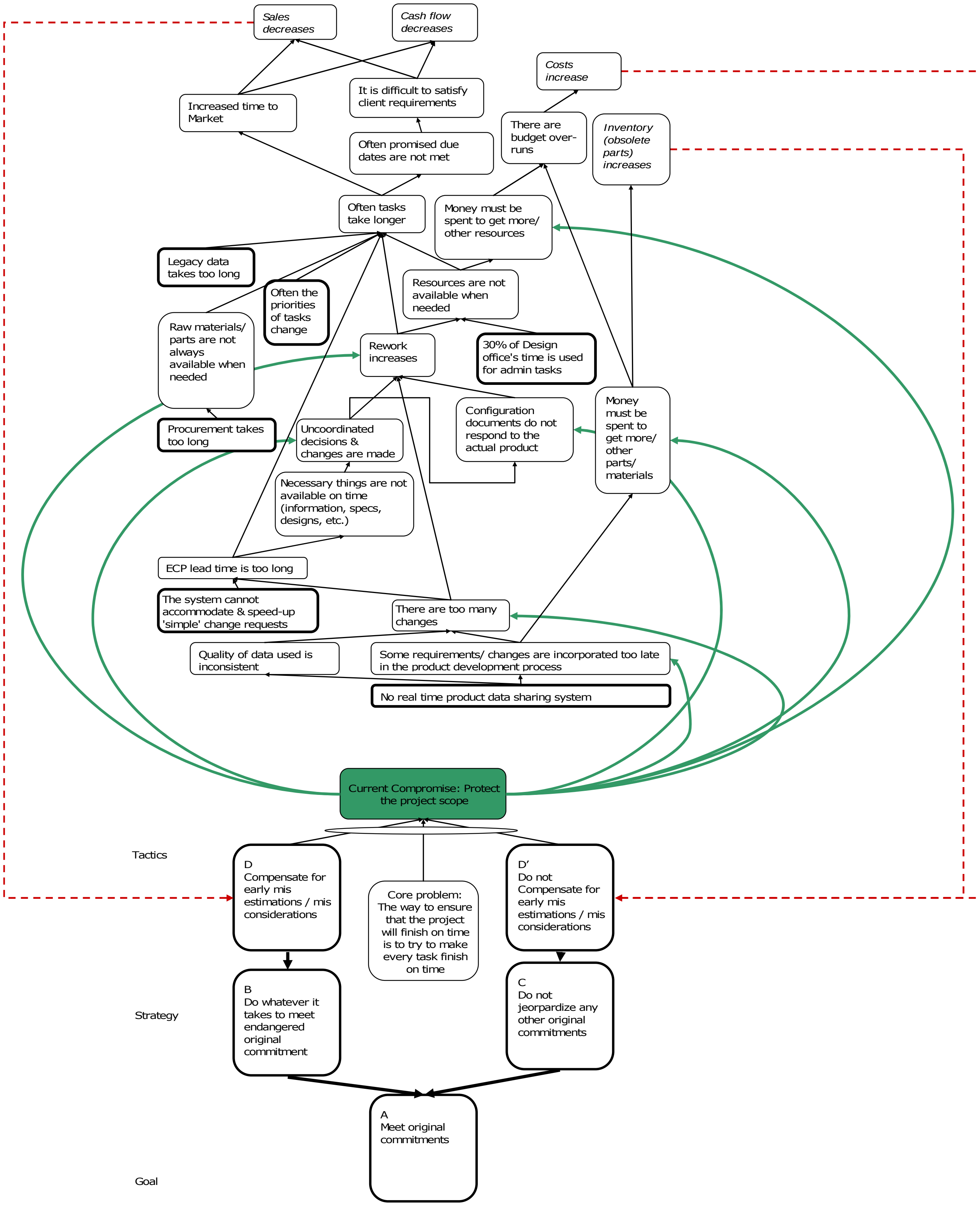


Diagram 8.2: The core conflict of DAS

Current policies, measurements and behaviours:

A workshop was held to identify the current Policies, Measures and Behaviours (PMB's) in DAS. The main policies and measures are given in Table 8.2:

- The program managers' performance is measured according to: whether a 30% profit volume is being made, milestones are being reached and due dates met.
- In the Engineering, Engineering Services and the production department the efficient utilisation of the available employees or resources are measured according to hour recovery.
- Support functions such as the procurement, IT and human resources departments are measured according to cost and ensuring a minimum headcount. The procurement department is measured on keeping stocks low.

Function / Department	**Policy**	**Measure**
Programs	Make 30% profit volume	Profit volume and schedule
Engineering	Keep employees full time busy on direct work	Hour recovery
	Do all design development and use resources efficiently	
Engineering Services	Keep employees full time busy on direct work	Hour recovery
Production	Keep employees full time busy on direct work	Hour recovery
Support (procurement, HR...)	Find the lowest price; keep headcount down	Cost
	Keep stock levels low	

Table 8.2: Departmental Policies and Measures

The ultimate goal of DAS is to increase company profits. In order to achieve this it is necessary to increase sales, but also to decrease costs. The company's drive to improve is filtered down to the departments by pressuring them to improve performance.

The current policies and measures are primarily focused on measuring the performance of the departments separately. It is, however, also the cause of inherent conflicts that exist between departments within DAS and ultimately hinders company improvement. The inherent conflicts are illustrated by two scenarios and portrayed in Figure 8.2:

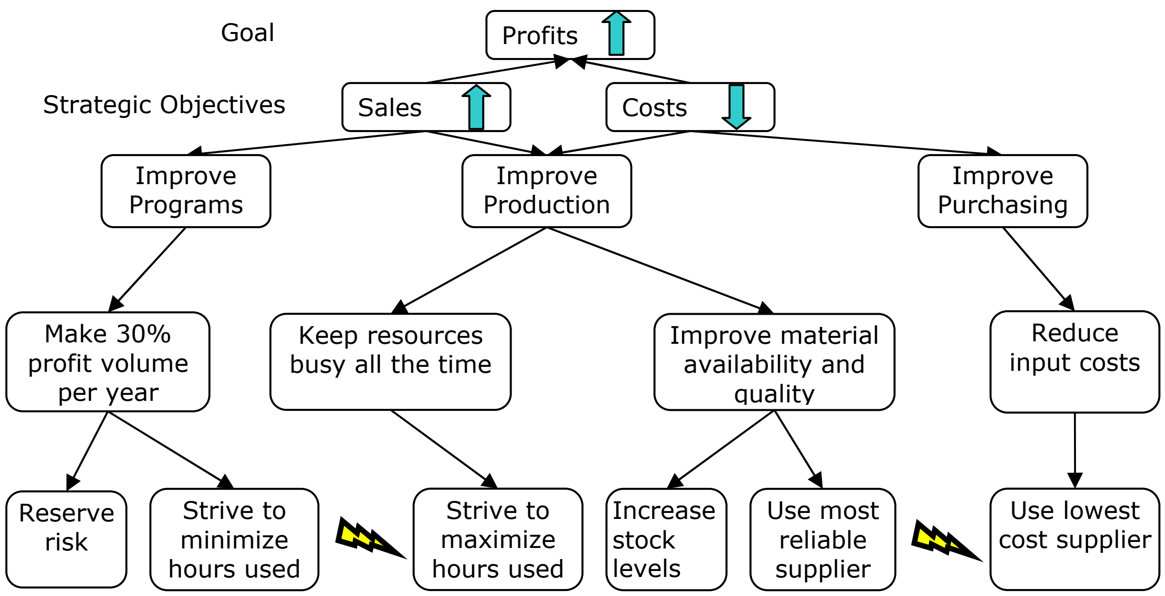


Figure 8.2: Inherent conflicts in DAS

Scenario 1:

For the program managers', improvement implies achieving 30% profit volume per year. In order to achieve this, program managers take actions such as reserving funds to account for project risk and/or striving to minimize the hours used for a project (resources charge per hour and therefore minimizing the hours used for a project implies less costs for the program managers).

However, for the production department, improvement implies making sure all resources are always busy. Therefore the production department strives to maximize the hours used for a project.

With the current policies and measures, the program managers strive to minimize the hours used on a project. On the other hand, the production department strives to maximize the hours used on a project. In this way, the current policies and measures cause conflict between the two departments.

Scenario 2:

For the production department, improvement is also achieved through improving the material availability and quality. Production can achieve this through taking actions such as using the most reliable supplier and/or increasing stock levels.

The procurement department's performance, however, is measured by cost and inventory reduction. If pressure is placed on this department to improve its performance, it will strive to minimize costs and inventory. In order to minimize input costs, the procurement department will strive to use the lowest cost supplier.

With the current policies and measures, the production department strives to use the most reliable supplier and/or strives to increase stock levels. On the other hand, the procurement department strives to use the lowest cost supplier and to decrease stock level. The current policies and measures cause conflict between the two departments.

Considering these two scenarios, it is apparent that the current policies and measures in DAS will hinder any efforts of internal collaboration. Although the intention of the policies and measures are good, it can be seen that in the current situation, the departments are not aligned with the goal of the company. This contributes to the current predicament of DAS.

<u>Current Product data management policies:</u>

Another source of old rules was the product data management formal and informal policies and processes.

- The engineering change management consists of a mix of electronic workflow and manual process steps. Configuration management (CM) processes are managed and executed manually. However, these procedures are time consuming. Sometimes shortcuts are used and then the formal procedure is updated at a later stage.
- Hard copies are used to communicate data: a 3D master model is used to generate engineering drawings and verify assembly fits and these drawings are then used to communicate product data to subsequent processes, such as manufacturing.
- Sometimes product decisions are made on assumptions, because product data is stored in multiple places which are disconnected from each other.
- Product data is communicated sequentially (due to the functional product development approach).

<u>Current project management policies:</u>

- Adding safety will improve project due date performance
- By starting as soon as possible there is a bigger chance of making the due date
- Multitasking is good

A summary of the DAS's current rules are given in Table 8.3.

Rules Classification	**What rules helped to accommodate the limitation?**
Paradigm	Functional Product Development
	Locally focused project management principles
PDM formal and informal Policies	Use hard copies to communicate data
	Short cuts can be used and then the formal procedure is updated at a later stage
	Product decisions are made on assumptions
Current Project Management Policies	Adding safety will improve project due date performance
	By starting as soon as possible there is a bigger chance of meeting the due date
	Multitasking is good
Measurements	Local/ function specific measures are used
Behaviour	Over the wall mentality
	Doing what is good for the function/department

Table 8.3: DAS current rules

4.1.2 Identifying the rules that should be used now

Subordination is enforced by developing constraint aligned rules and metrics.

<u>Paradigms:</u>

In Chapter 6 it is proposed that the CE paradigm must be established with the implementation of PDM Software.

A holistic management solution is necessary to support the cross-functional PDM initiative. In addition the core conflict of DAS was identified as being the project management core conflict. The Critical Chain (CC) project management approach was designed to address this core conflict. It can also help to ensure that different parts of the product lifecycle/ project can judge the impact of their actions on the system as a whole. Critical Chain project management was therefore chosen as the holistic management solution to be implemented with the implementation of PDMLink.

Policies:

New product data management policies will have to be enforced. The software system capabilities should be taken into account when determining the new policies.

The basic PDMLink capabilities are:

1. Control product information
2. Create, edit and manage product configurations and associated BOM's
3. Perform CMII-compliant engineering change management process
4. Automate product development business processes
5. Facilitate collaborative product development activities
6. Manage heterogeneous CAD data and integrate with other enterprise systems

The basic policies that must be implemented to support and enable the PDMlink capabilities are given in Table 8.4.

PDMLink capability		**Product data management policy**
1	Control product information	All product data generated across the product lifecycle must be stored in the PDM system. Access privileges to data must be managed.
2	Create, edit and manage product configurations and associated BOM's	Implement CMII configuration management policies
3	Perform CMII-compliant engineering change management process	Implement CMII change management policies
4	Automate product development business processes	All checks and suggestions will be done electronically using the visualization tools and mark-up functions. The electronic change management process will be enforced. The electronic configuration management process will be enforced.
5	Facilitate collaborative product development activities	Implement Concurrent Engineering policies Access to the PDM software must be given to all parties involved in the product lifecycle

Table 8.4: Basic product data management policies

Policies are necessary that will support the establishment of the Concurrent Engineering approach to product development. It is imperative that functions such as manufacturing and support are involved earlier in the product development process.

Comparing the company's current capabilities to an ideal CE environment will identify areas that need improvement and policies that will have to be enforced. Examples applicable to DAS are:

- Always promote team membership and contribution
- Promote business interrelationships
- Ensure alignment of responsibility and authority
- Enable tasks to run in parallel
- Use lessons learned and feedback from previous projects
- Develop company-wide product data terminology
- Focus product development on customer satisfaction

Specific policies that will support the establishment of the new CMII configuration management process and CMII change management process, throughout the Product lifecycle, are:

- Data integrity must become a quality issue (Guess, 2002:94).
- Process improvement is measured by ability to change faster and/ or document better (Guess, 2002:21).

The Critical Chain Project Management (CCPM) paradigm will have to be enforced by certain policies:

- Identify what is necessary and sufficient for the next project task to begin
- Use critical chain project planning: Rebuild each project PERT according to protected critical chain.
- Do not turn estimates into commitments (to prevent student syndrome and Parkinson's Law).
- Critical chain tasks are performed with a relay runner work ethic.
- Use the buffer and buffer management to determine when to take action.
- Prioritize tasks in order to protect due dates
- Choke the release of projects according to the capacity of the critical resource (to prevent 'bad' multitasking)

Measurements:

Holistic measures are necessary that can help to judge the impact of a part on the system as a whole. These measurements include (refer to Chapter 4):

- Throughput (this directly measures the subordination to the market)
- Investment
- Operating Expenses
- Due Date Performance
- Quality
- Lead Time (Measure resource on how quickly they perform the task after it is available to work on)
- Throughput Rand Days

Furthermore, buffer management (BM) is implemented as a part of the Critical Chain project management and it will ensure that work is prioritized in order to protect project due dates. Feedback is given by the BM statistics, which is the enabler for a Process Of OnGoing Improvement (POOGI).

CMII principles that are imbedded in PDMLink software necessitates measuring the change process lead time and measuring data quality.

Behaviours:

- Collaboration
- Doing what is good for the product lifecycle/ project/ company as a whole.
- New PDMLink specific work procedures

The PDMLink specific work procedures consist of:
- Work procedures that are governed by the architecture or build of the software
- Work procedures that are governed by the approaches or models embedded in the software system
- Work procedures that are governed by proposed best practices

  The Product Development System (PDS) assessment (Refer Appendix 3: PDS Assessment) identifies best practices for the PTC product development system, that can increase the potential benefit achieved with the implementation. The implementation of the best practices should be prioritised according to the potential increase in Throughput for the company.

A summary of the DAS's new rules are given in Table 8.5:

Rules Classification	**What rules should be used now?**
Paradigm	Concurrent Engineering
	CCPM principles
Policy	New product data management policies
	New CMII configuration management policies
	New CE policies
	New CCPM policies
Measurements	Holistic measures
Behaviour	Collaboration
	Doing what is good for the project/company as a whole
	New PDMLink specific work procedures

Table 8.5: DAS new rules

4.2 The solution:

The new rules originate from three different technologies as portrayed in Figure 8.3.

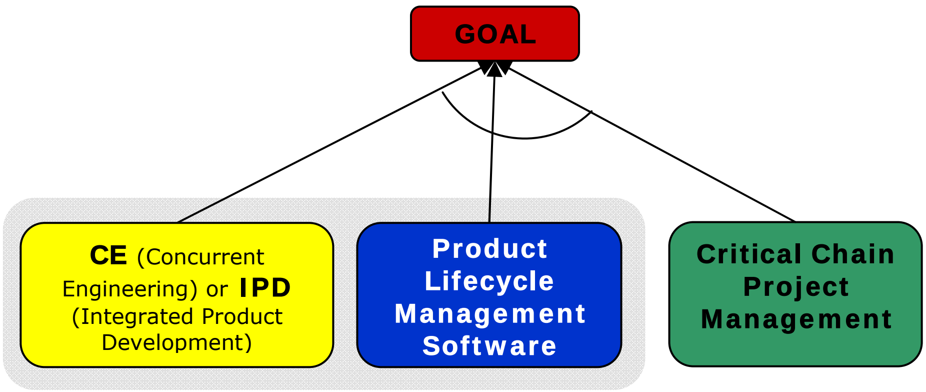


Figure 8.3: The three technologies used to develop the solution

The implementation of the new rules with the implementation of the PDMLink software will result in bottom-line benefit for DAS. The cause and effect logic to substantiate this claim follows and is portrayed in a FRT in Diagram 8.3 (Refer to Appendix 5: DAS FRT for a bigger version of the diagram). The future reality tree is written in the language of a process of ongoing improvement.

PDMlink capabilities can physically make it possible for all requirements/ changes to be incorporated more and more early in the product development process, but this will only become a reality with a CE approach to product development. The holistic measure TRD prevents lateness of tasks, but also places accountability for problems at the right place. As a result, this ensures that work is checked thoroughly, before being passed on to the next task. This measure will therefore support the achievement of all requirements/ changes that are incorporated more and more early in the product development process.

PDMlink capabilities can physically help to ensure that a consistent quality of data is used. The CCPM principle of identifying what data is necessary and sufficient for the next project task to begin, as well as measuring data quality, will support the achievement of the desired effect of having a consistent quality of data.

The desired effect of necessary things that are available when needed is achieved due to the following: (1) a consistent quality of data, (2) a critical chain project plan, (3) a CE approach to product development and (4) certain PDMLink capabilities.

Necessary things that are available when needed, a consistent quality of product data and requirements/ changes that are incorporated more and more early in the product development process, will result in fewer and fewer changes.

The PDMlink capabilities can physically manage the configuration process. This, combined with the establishment of the CMII process and principles, as well as the measurement of data quality will make it possible for configuration documents to respond to the actual products.

PDMLink provides capabilities that, if combined with the implementation of the new change process principles, will result in a system that can accommodate 'simple' change requests. If this is combined with the desired effect of fewer and fewer changes, then an improvement in Engineering Change Proposal (ECP) lead time will be seen. Process improvement, per CMII, is measured by the ability to 'change faster and/ or document better (Guess, 2002:21). Measuring and monitoring the change process lead time is therefore essential. In addition, a simple buffer management system can be used to drive the continuous improvement of the ECP lead times.

If all requirements and changes are incorporated more and more early in the product development process, it will lead to a decrease in money spent on getting additional or different parts and materials. If this desired effect is combined with the PDMLink capability that enables part re-use, the result is a decrease in inventory.

With configuration documents that respond to actual products, a decrease in the amount of changes and an improvement in part re-use, the inevitable result will be a decrease in rework.

PDMlink capabilities streamlines design office administrative tasks. If this is combined with appropriate project execution behaviours (which imply that there is no 'bad' multitasking, student syndrome, or Parkinson's law) and decreasing rework is a reality, then the result is resources that are more and more available when needed.

If resources become more and more available then the amount of money/funds spent on getting more/other resources will decrease. If this is a reality, combined with the fact that less money must be spent on getting more/other parts and materials, then budget over-runs will decrease. The final outcome is a decrease in costs.

If the legacy data is captured or at least catalogued in the PDMlink system then legacy data will take less time to be retrieved.

With critical chain project management, buffer management and measures in place, program managers will be able to prioritise tasks to protect project due dates. Therefore, priorities between tasks will be clear.

The critical chain project plan, combined with the procurement department's ability to have real time product data, will help to ensure that the procurement of parts and materials are on time more and more often. This will contribute to ensuring that raw materials/ parts are available when needed.

Tasks will take less and less time to be completed due to the following: (1) raw materials/ parts are available when needed, (2) legacy data takes less time to be retrieved, (3) priorities between tasks are clear, (4) ECP lead times are decreasing, (5) the amount of rework is decreasing and (6) resources are, more and more often, available when needed. This desired effect will lead to reduced time to market. Furthermore, promised due dates will met because of (1) tasks taking less time to be completed, (2) critical chain project planning and (3) due date performance being measured and improved. This will contribute to customer satisfaction.

In addition, if resources are more and more often available, it is possible to do more concept iterations at the start of the project in order to ensure client satisfaction. A CE approach to product development, combined with good quality measures, will support this process.

Diagram 8.3: DAS FRT

A reduction in the time to market and satisfied customers both result in increased sales and an increase in cash flow. A focus on measuring Throughput will support the improvement of these strategic objectives. The resulting increase in sales and decrease in cost will positively impact the bottom-line of DAS.

4.3: Developing the transition plans:

The next step of the implementation methodology consists of the development of action plans that will take the company from the current reality to the future reality.

The development of the transition (action) plans will only take place after the acceptance and refinement of the future reality tree. This step was not done as a part of the DAS analysis mainly due to the practical nature of the exercise. The analysis thus far was a theoretical exercise. The differences between the reality of the implementation and the N&S solution approach presented here will be highlighted in following Chapter.

Chapter 9:

METHODOLOGY APPLICATION VALIDATION & RECOMMENDATIONS

This chapter begins with a presentation of the state of the current implementation. Thereafter, the current implementation approach is analysed using cause and effect logic, in order to verify the validity of the implementation methodology approach. Lastly, a number of recommendations are made: areas of the current implementation approach that can be improved or changed in order to ensure that benefit will be achieved using this specific implementation, are identified.

9.1 IMPLEMENTATION INFORMATION

The Engineering Services department used Pro/INTRALINK software to manage the product data locally. PDMlink is the next generation of PDM software.

The need for a holistic product data management tool was recognized in DAS. The SAP PDM module was considered, but it did not satisfy all the PDM requirements of DAS and was therefore not implemented.

The Engineering Services department of DAS decided to implement the PDMLink software when the company decided to change to another ERP system. This new ERP system did not have any PDM functionality.

The PDMLink internal champion is the head of the Engineering Services Department. The implementation was only done locally in the Engineering Services department, with a possibility to role out across the entire product lifecycle in subsequent implementation phases. This would only be a possibility if the limited local implementation was successful.

The DAS PDMLink implementation in the Engineering Services Department is experiencing difficulties. Therefore, the possibility of continuing with the next phase of the implementation is slim.

9.2 THE CURRENT IMPLEMENTATION APPROACH

The objectives, scope and expectations of the implementation was focused locally on the Engineering Services Department. The improvements were measured locally.

The local focus caused that the performance of the new software was compared to the performance of the previous local software package that the Engineering Services department used.

As mentioned earlier, the Engineering Services department used PTC's Pro/INTRALINK software before implementing PDMLink. If the two software packages are compared, a large number of the functions applicable to the Engineering Services environment are very similar in both packages. The purpose of each of the software packages is, however, vastly different.

The Pro/INTRALINK software version that the Engineering Services department used before PDMLink was built for providing the product data management and product data processes to co-located Pro/ENGINEER workgroups.

PDMLink goes one step further, by expanding the reach of the benefits of product data management across the entire product lifecycle. The software structure has changed significantly, in order to allow holistic product lifecycle data management ability. It is now built on a clean, modern Web-based architecture.

The reality is that pure PDMLink data management tasks are marginally slower than pure Pro/INTRALINK data management tasks when operating in a LAN environment. Pure PDMLink data management tasks are significantly faster than pure Pro/INTRALINK 3.x data management tasks when operating in a WAN environment (Parametric Technology Corporation. 2005).

Thus the studies that compared the two software packages showed that the PDMLink software performance might be slower when processing certain tasks, but when it is placed in a holistic product lifecycle environment, benefits are reaped for the product lifecycle as a whole.

Therefore, it is a reality that if the PDMLink software is judged solely on the processing time of certain tasks within the Engineering services department, it will not meet expectations. This is what led to DAS's dissatisfaction with the new software.

Most of the effort associated with the implementation of PDM software is usually concentrated on implementing the software in departments with functions similar to those of the Engineering and Engineering Services departments. This is due to the fact that these departments generate most of the product data. However, it is also true that due to the holistic reach and focus of the software, the benefit of the technology is revealed in departments/ functions other than those where the heart of the implementation lies. Without holistic measures, the actual benefit realised with the implementation will never be acknowledged.

9.3 IMPLEMENTATION METHODOLOGY VALIDATION

The reality of the DAS PDMLink implementation is portrayed in Diagram 9.1. (Refer to Appendix 6: The CRT of the current DAS PDMLink implementation approach for an A3 version of the diagram).

Due to the fact that the PDMLink implementation is limited to the Engineering Services department, there is no system to manage the product data across the product lifecycle. Therefore the PDMLink system cannot assist in ensuring that a consistent quality of data is used across the product lifecycle. In addition, due to the fact that no rules were changed with the implementation of PDMLink, it may be deduced that no data quality measure was implemented and thus there is at present no drive to improve it. Thus the quality of product data used is not consistent across the product lifecycle.

The limited implementation causes the sharing of product data to remain a cumbersome process, thus necessities (such as information, specifications, designs, etc.) are still not always available on time.

Due to the fact that no rules were changed with the implementation of PDMLink, DAS still has a functional orientation and still uses current measurements, which have been proven to cause inherent conflicts and inhibit collaboration. A product data management system that spans the entire product lifecycle is an enabler for a CE approach. The current measures and functional orientation of the company combined with the limited implementation of the PDMLink software, leads to the CE approach that is not yet a reality. Thus manufacturing and support are not yet involved earlier in the product development process and thus requirements/ changes are still incorporated too late in the product development process. Furthermore, no measurement such as a TRD measurement was implemented and as a result there is no drive to improve.

The requirements/ changes that are incorporated late in the product development process, the unavailability of the necessary product data when needed and the inconsistency of product data leads to many changes that have to be made. In addition, it leads to high levels of rework. The rework occupies resources which lead to increases in expenses to get more/ other resources. This, combined with the expenses associated with the changes that are made late in the development (buy more/ other parts/ materials) process, leads to budget overruns and increased costs.

In DAS's case, the configuration and change management procedures were streamlined only within the Engineering Services department, but the bulk of the processes (that involved all other departments) were still done according to the previous manual system. The power of PDM software of removing non-value adding tasks and streamlining product data processes did therefore not realise any benefits. The need to interface with the new system may even have increased the work associated with these processes. Thus no improvement was made in the ECP lead times.

Due to the limited PDMLink implementation, other departments, such as the procurement department, do not have access to real time product data. Therefore raw materials/parts are not always available when needed. Combined with no clear task priorities (due to no changes in the rules) and the long ECP lead times, the result is that tasks take longer than expected.

The inevitable result of tasks that take longer than expected is due dates that are not always met. In addition, the project planning paradigm is still focused on finishing tasks on time and the project due date is not protected. There is also no Due Date Performance (DDP) measurement, thus there is no drive to improve it.

Poor DDP leads to unsatisfied customers, which results in lost current and future sales. A decrease in sales combined with an increase in costs results in decreased profits. Thus the current implementation approach will not lead to any improvement in the company bottom line.

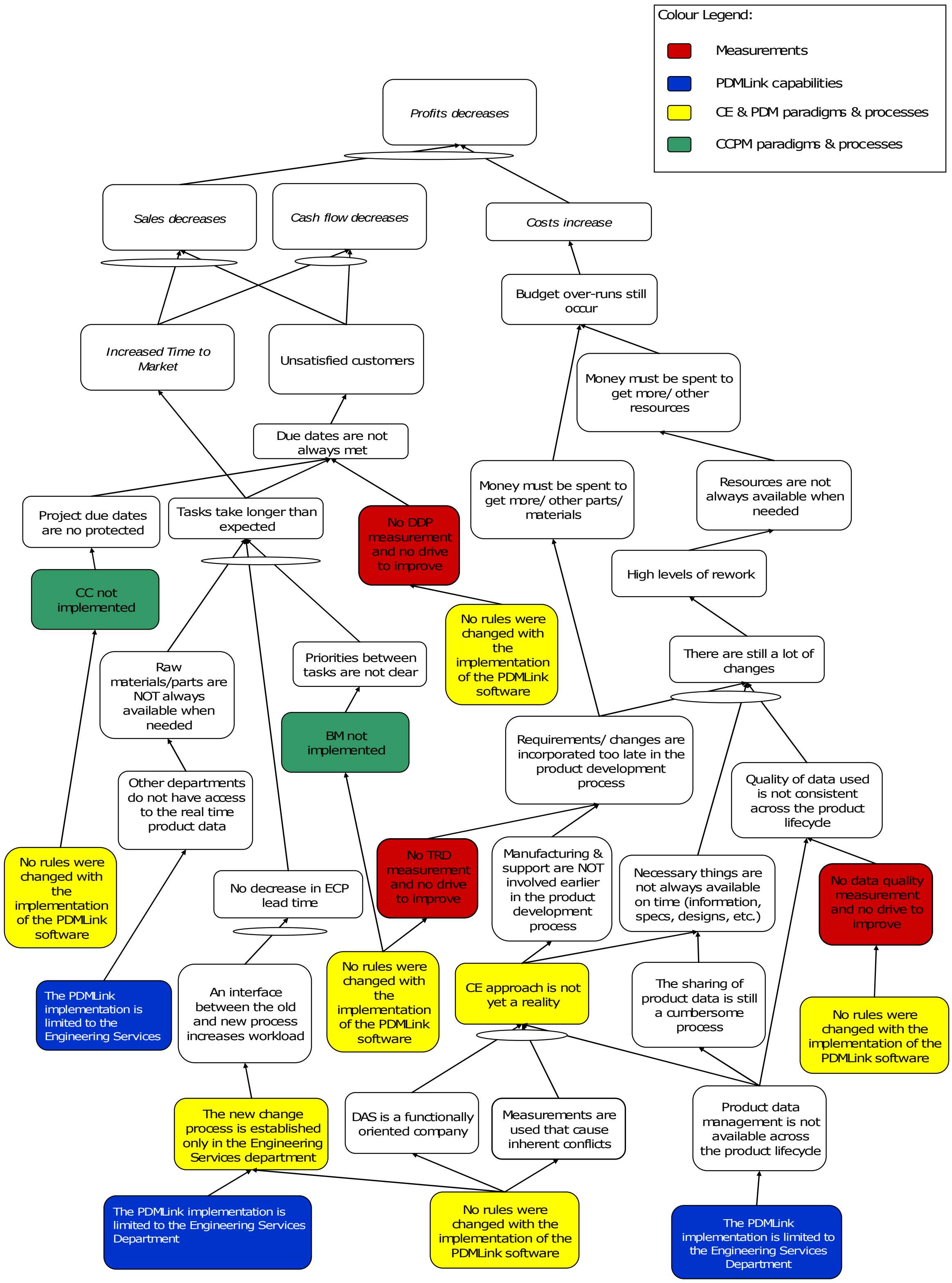


Diagram 9.1: The CRT of the current DAS PDMLink implementation approach

It can be derived from the discussion above that no value was added with the PDMLink implementation due to two main reasons:

- The limited implementation of the PDMLink software.
  The power of the new software was not defined and communicated to DAS. PDMLink provides an enterprise-wide product data management solution that involves the management of product data and product data processes. The software requires a holistic focus and scope. It requires top management buy in and support. It requires holistic measurements.
- No rules were changed with the implementation of the software.

The implementation methodology approach to the implementation of PDM software addresses exactly these two deficiencies through establishing the necessity and sufficiency of the software implementation.

The DAS PDMLink implementation is an example of an implementation that failed due to the wrong implementation approach.

9.4 RECOMMENDATIONS

The goal of Automated Reasoning (AR) was to achieve a full-phased implementation. AR started to realise the need for moving towards selling value and long term business solutions for their customers rather that just focusing on a purely technological point of view. However, the vehicle to ensure that the value is realised was not in place yet.

The N&S solution was originally developed to ensure the achievement of bottom-line benefits for ERP implementations. The N&S analysis of the DAS PDMLink implementation was done as a research project and it resulted in a roadmap (refer to Figure 7.2). The roadmap was developed to assist with the achievement of bottom-line benefit for this specific implementation.

With the current implementation approach, the software capabilities have not been exploited. The N&S Analysis (refer to Diagram 8.3) proved that PDMLink can add value. The following recommendations were made in order to realign the implementation to the power of the software and to start the process of establishing the sufficiency of the software implementation. The recommendations, therefore, address the deficiencies of the current implementation approach.

1. The current implementation contract specifies a phased implementation. The first phase consists of limited software user licences. In accordance with this contract it was suggested that the user licences for the first phase of the implementation be spread

across the entire product lifecycle. Thus the first phase should consist of implementing PDMLink across the entire product lifecycle for one or more of the current product development projects. In this way the power of the software can be fully utilized and a holistic product lifecycle oriented approach to the implementation is possible. This, together with the implementation of new holistic rules, will in turn enable the achievement of holistic benefits.

2. Engineering Services: Changing the rules

The measurements and management principles used in the Engineering Services Department should be replaced with holistic measurements and focus.

The high levels of multitasking in the Engineering Services Department are just one indicator of the high levels of WIP in the Engineering Services department. Most of the work done in the engineering department is engineering change proposals (ECP). An undesirable effect experienced in DAS is that the ECP process takes too long. According to Little's law, the high levels of WIP in the Engineering Services department are an indication of the long lead times.

A solution was suggested to focus on the improvement of ECP lead time. The steps involved are:

- The implementation of Throughput Rand Days and ECP lead time measurements.
- The implementation of Critical chain project management principles locally and a simple buffer management system specifically focused on the engineering change process.

This recommendation will help to improve ECP lead times and exploit hidden capacity in the Engineering Services department through the implementation of holistic management principles. These results are in accordance with the goal of the implementation and the Engineering Services department.

The recommendation, therefore, creates awareness of the need to change the rules with the implementation of the software in order to meet implementation goals.

3. Aligning product development rules to the PDMLink capabilities

PDMLink does take longer than Pro/INTRALINK to do certain tasks in a local environment. However, there are some improvements to processes and procedures that can be made that will improve the local PDMLink performance. It was suggested that new software product development rules should be developed and implemented as a part of the PDMLink implementation.

The steps involved are:

- A workshop will be held to identify the procedural changes necessary in the Engineering Services department. The PDMLink implementers and the key role players in the Engineering Services department must be involved.
- The development of DAS specific training material
- Implementation of the new procedures

Chapter 10:

SUMMARY AND CONCLUSION

10.1 SUMMARY OF FINDINGS

Using analysis, the power of PDM Software was defined. The PDM software addresses core limitations experienced in the product data management environment today. It was proven that, by removing these limitations and supporting this removal by new and/or changed rules, the implementation of PDM software can bring bottom-line benefit (see Chapter 6). The extent of organisational change that is necessary with the implementation of PDM was identified.

- An implementation methodology was developed based on the N&S principles.
  The implementation methodology was applied to the DAS PDMLink implementation. The results of the real implementation provided proof of the need to apply the N&S principles to an implementation. The implementation methodology is proposed as a tool to enable the application of the N&S Solution.

- This thesis proposes that the N&S Solution can enable software sellers to ensure that they are selling and guaranteeing value to their customers. It is a fact that this approach to selling software is much more resource and time intensive as opposed to merely installing software and providing user training. Selling value requires the selling of organisational change. The internal changes necessary for software providers to attempt selling value and organisational change are extensive. It requires redefining the company, its policies, procedures and focus.

- On the other hand, this thesis proposes that the N&S solution can enable software buyers to choose the most applicable software solution. More importantly, it can enable companies to achieve success with any improvement initiative.

All the research objectives of the project were achieved.

This thesis makes a contribution to the research regarding the deployment and implementation of PLM software. It proposes the implementation of a new holistic management paradigm with the implementation of PLM, in order to ensure that bottom-line benefit is achieved with the implementation of PLM technology.

Recommendations for further research:

- The generic old rules and new rules that were identified in the generic N&S discussion of PDM software (Chapter 6) should be validated. The list can still be expanded.

- The PDM implementation methodology was theoretically validated. It has not yet been validated by applying the methodology from the outset to an implementation.

- The PDM implementation methodology was applied to a specific case. DAS is a projects company. Therefore the Critical Chain Project Management TOC solution was applicable. The PDM implementation methodology can be tested on cases where other TOC solutions are applicable. The PDM implementation methodology can also be tested on a company with no need to change their mode of management i.e. holistic management principles are already applied.

10.2 TO CONCLUDE

Referring back to the common reasons for failure listed in Chapter 3, the reasons can be categorized according to two groups. The first group consists of situations that exist due to the failure to determine the necessity of the software and the second due to failure in determining the sufficiency of the software.

An analysis to define the power of the software and the limitations that it diminishes will ensure a clear understanding of the problem at hand. In addition, it will support the formulation of a clear objective and cross-functional scope for the implementation. Lastly, it will support the process of getting top management buy in.

Analysis of the sufficiency of the software implementation will ensure awareness of the organisational changes that must be made and will support the development of a focused implementation plan.

Many software implementations today are focused on how the software can support or enhance the current business processes. The N&S solution provides the challenge to focus on how current business paradigms, processes, policies, measures and behaviours should change to benefit from the new software applications.

LIST OF REFERENCES

Ameri, F. and Dutta, D. 2004. *Product Lifecycle Management Needs, Concepts and Components*, Technical Report. [Online]. Available: http://www.plmdc.engin.umich.edu [5 December 2005]

AMR Research Staff. 2003. *Improving Innovation and Cash Flow in the High-Tech Manufacturing Industry*. [Online]. Available: http://www-03.ibm.com/solutions/plm/doc/content/bin/IBM--high-tech.pdf [5 December 2005]

Asklund, U., Crnkovic, I. and Dahlgvist, A.P. 2003. *Implementing and Integrating Product Data Management and Software Configuration Management*. Norwood: Artech House, Inc.

Bernus, P., Nemes, L. and Williams, T.J. 1996. Architectures for Enterprise Integration. London: Chapman and Hall.

Bertoline, G. R., Wiebe, E. N. and Miller, /C. L. 2002. *Fundamentals of Graphics Communication, 3/e*. [Online]. Available: highered.mcgraw-hill.com/sites/0072322098/student_view0/glossary_p.html [30 March 2005]

Brown, C. and Vessey, I. 1999. ERP implementation approaches: toward a contingency framework. *Proceeding of the 20th international conference on Information Systems*, Charlotte, North Carolina, United States, 12-15 December 1999 ,411 – 416. Atlanta: Association for Information Systems

Bruges, P. 2002. ERP implementation methodologies, *a paper presented at MIS 488, Information Systems Analysis*, [Online]. Available: www.umsl.edu/~sauter/analysis/488_f02_papers/erp1.htm [20 August 2006]

Burkett, M.,O'Marah, K. and Carrillo, L. 2003. *CAD Versus ERP Versus PDM: How to Best To Anchor a PLM Strategy?* [Online]. Available: http://www.ptc.com/WCMS/files/17636en_file1.pdf [20 August 2006]

Chase, R.B., Aquilano, N.J. and Jacobs F.R. 2001. *Operations Management for Competitive Advantage*. 9th ed. New York. McGraw-Hill.

Cox, J.F., Mabin, V.J. and Davies, J. 2005. *A case of personal productivity: Illustrating methodological developments in TOC.* Human Systems Management 24: 39–65.

Crow, K. 2001a. *Product Development implementation*, DRM Associates Web resources. [Online]. Available: http://www.npd-solutions.com/.html [12 December 2005]

Crow, K. 2001b. *Product Development Metrics List*, DRM Associates Web resources. [Online]. Available: http://www.npd-solutions.com/.html [12 December 2005]
Downes, L. 2002. *The Metamorphosis of Information: Information, not physical goods, will soon form the core of every industry's new supply chains* [Online]. Available: http://www.optimizemag.com/issue/008/strategies.htm [5 December 2005]

Garetti, M., Terzi, S., Bertacci, N. and Brianza, M. 2005. *Organisational change and knowledge management in PLM implementation*, *Int. J. Product Lifecycle Management*, 1, (1):43–51.

Goldratt, E.M., Schragenheim, E. and Ptak, C.A. 2000.*Necessary but not sufficient*. Great Barrington: The North River Press.

Goldratt, E.M., Barnard, A. and Goldratt, R. 2004. *Introduction to Theory of Constraints*.[Electronic presentation - Brochure]. E.M. Goldratt

Goldratt, E.M. 2003a. *TOC Insights into Distribution*, [Electronic study material]. Goldratt Marketing Group.

Goldratt, E.M. 2003b. *TOC Insights into Finance and Marketing*, [Electronic study material]. Goldratt Marketing Group.

Goldratt, E.M. 2003c. *TOC Insights into Project management*, [Electronic study material]. Goldratt Marketing Group.

Goldratt Group. 2005. *Confidential report: DAS Viable Vision*.

Goss,T. 1996. *The Last Word on Power: Executive Re-Invention For Leaders Who Must Make The Impossible Happen*. New York: Doubleday Books.

Guess, V. C. 2002. *CMII for Business Process Infrastructure*. Scottsdale: Holly Publishing.

Huijben, M. 2005a. *Data migraine*. Product Lifecycle Management e-zine 7(12) [Online]. Avaliable: http://www.johnstark.com/2PLM177.html [31 March 2005]

Huijben , M. 2005b. PLM and ERP: *Who owns the data?* Product Lifecycle Management e-zine 8(6) [Online]. Available: http://www.johnstark.com/2plm197.html [13 September 2005]

Kendall, G.I. 2005. Viable Vision: *Transforming total sales into net profits*. Florida: J. Ross Publishing.

Mabin,V., Davies, J. and Balderstone, S. 2005*. The Theory of Constraints: A methodology apart? - A comparison with selected OR/MS methodologies*, Omega – The International Journal of Management Science 33: 506 – 524

MatrixOne. 2005. *MatrixOne Professional Services.*[Brochure]. MatrixOne

Mines, C. 2005. *The Seeds Of The Next Big Thing: Sketching The Fourth Wave Of Growth For The Technology Economy*. [Online]. Available: http://www.forrester.com/Research/Document/Excerpt/0,7211,37264,00.html [5 December 2005]

Necessary but not Sufficient CD Series: *The basic assumptions of TOC*. 2002. Goldratt's Marketing Group [CD ROM]

Necessary but not Sufficient CD Series: *The role of software*. 2002. Goldratt's Marketing Group [CD ROM]

Newbold, R.C. 1998. *Project Management in the Fast Lane*. Florida: CRC Press

Parametric Technology Corporation (PTC). 2005. *Less Wait. More Create. How Pro/INTRALINK® 8.0 Delivers Improved Productivity*. [Brochure].PTC.

Parr, A. N. and Shanks, G. 2000. A Taxonomy of ERP Implementation Approaches. *Proceedings of the 33rd Hawaii International Conference on System Sciences*, Hawaii, 4-7 January 2000, 1-10. Washington: IEEE Computer Society

Patrick, F.2000. *Focused Performance: Critical Chain Basics*. [Online] Available: http://www.focusedperformance.com/articles/cc01.html [20 August 2006]

Pfeifer, T. and Grundmann, T. 2007. Innovative Process Chain Optimization (IPO) with TRIZ and TOC to increase the added value within the production. *Proceedings of the International Conference on Competitive Manufacturing 2007*, Stellenbosch, South Africa, 31 January – 2 February 2007, 211-216. Stellenbosch: Global Competitiveness Centre

Product Lifecycle Management Worldwide Outlook: Market Analysis and Forecast Through 2008. [Online]. Available: http://www.arcweb.com/research/ent/plm.asp [31 March 2005]

Product Development System. [Online]. Available: http://www.ptc.com/products/product_development_system.htm [30 March 2005]

Ravi M. Rangan, R. M., Rohde, S.M., Peak, R., Chadha, B. and Bliznakov, P. 2005. Streamlining Product Lifecycle Processes: A Survey of Product Lifecycle Management

Implementations, Directions, and Challenges. *Journal of Computing and Information Science in Engineering*, 5: 227-237
Salustri, F.A. *Product Lifecycle Management*. [Online]. Available: http://deed.ryerson.ca/x/bin/xiki/View/Research/ProductLifecycleManagement [4 April 2005]

SAP AG. 2005. *mySAP™ PRODUCT LIFECYCLE MANAGEMENT: SOLUTION OVERVIEW*. [Brochure]. SAP AG

SAP AG. 2006. *SAP® CONSULTING AND SAP EDUCATION SERVICES PORTFOLIO 2006: Overview and Detailed Service Descriptions*. [Brochure]. SAP AG

Scheinkopf, L. 1999. *Thinking for a change*. Florida: St Lucie Press.

Sellgren U., and Hakelius, C. 1996. A survey of PDM implementation projects in selected Swedish industries, *Proceedings of ASME Design Engineering Technical Conference*, Irvine, California, 18-22 August 1996,

Smith, D. 2000. *The Measurement Nightmare: How the theory of constraints can resolve conflicting strategies, policies, and measures*. Florida: St Lucie Press.

Stark, J. 2005a. *Product Lifecycle Management: 21st Century Paradigm for Product Realisation*. London: Springer-Verlag

Stark, J. 2005b. *A September 2005 Definition of PLM*. Product Lifecycle Management e-zine 8 (6) [Online]. Available: http://www.johnstark.com/2plm197.html [13 September 2005]

Sweet, W.N. and Kossiakoff, A. 2002. *Systems Engineering Principles and Practice*. Hobokon, New Jersey: John Wiley and Sons, Inc.

Turino, J. 1992. Managing concurrent engineering: buying time to market. New York: Van Nostrand Reinhold Publishing

Ulrich, K.T. and Eppinger, D. 1995. *Product design and development*. New York: McGraw-Hill

Wrenn, K.P. 2005. *Ensuring a Successful PLM Implementation –Whitepaper*. [Online]. Available: http://www.ptc.com/WCMS/files/30412/en/30412en_file1.pdf [20 August 2006]

APPENDICES:

APPENDIX 1: Traditional Product Development Measurements

TOC only makes use of a few holistic measurements to manage a system as opposed to conventional management approaches that use many, sometimes complex, measures to manage the different parts of the system. Measurements used in the product development environment include (Crow. 2001b):

Requirements and Specifications

- Number of customer needs identified
- Number of discrete requirements identified (overall system and by subsystem)
- Number of requirements/specification changes (cumulative or per unit of time)
- Requirements creep (new requirements / total number of requirements)
- Requirements change rate (requirements changes accepted / total number of requirements)
- Percent of requirement deficiencies at qualification testing
- Number of to-be-determined (TBD) requirements / total requirements
- Verification percentage (number of requirements verified / total number of requirements)

Electrical Design

- Number of design review changes / total terminations or connections
- Number of post-design release changes / total terminations or connections
- Percent fault coverage or number of faults detectable / total number of possible faults
- Percent fault isolation
- Percent hand assembled parts
- Transistors or gates designed per engineering man-month
- Number of prototype iterations
- First silicon success rate

Mechanical Design

- Number of in-process design changes / number of parts
- Number of design review deficiencies / number of parts
- Number of drafting errors / number of sheets or # of print changes / total print features
- Drawing growth (unplanned drawings / total planned drawings)
- Producibility rating or assembly efficiency
- Number of prototype iterations
- Percent of parts modeled in solids

Software Engineering

- Manhours per 1,000 software lines of code (KSLOC)
- Manhours per function point
- Software problem reports (SPR's) before release per 1,000 software lines of code (KSLOC)
- SPR's after release per KSLOC
- Design review errors per KSLOC
- Code review errors per KSLOC
- Number of software defects per week
- SPR fix response time

Product Assurance

- Actual MTBF / predicted MTBF
- Percent of build-to-packages released without errors
- Percent of testable requirements
- Process capability (Cp or Cpk)
- Product yield
- Field failure rate
- Design review cycle time
- Open action items
- System availability
- Percent of parts with no engineering change orders

Parts Procurement

- Number of suppliers
- Parts per supplier (number of parts / number of suppliers)
- % of standard or preferred parts
- % of certified suppliers
- Percent of suppliers engaged in collaborative design

Enterprise

- Breakeven time or time-to-profitability
- Development cycle time trend (normalized to program complexity)
- Current year percent of revenue from products developed in the last "X" years (where "X" is typically the normal development cycle time or the average product life cycle period)
- Percent of products capturing 50% or more of the market
- Percent of R&D expense as a percent of revenue
- Average engineering change cycle time

- Proposal win rate
- Total patents filed/pending/awarded per year
- R&D headcount and percent increase/decrease in R&D headcount

Portfolio and Pipeline

- Number of approved projects ongoing
- Development work-in-progress (the non-recurring, cumulative investment in approved development projects including internal labor and overhead and external development expenditures and capital investment, e.g., tooling, prototypes, etc.)
- Development turnover (annual sales divided by annual average development work-in-progress)
- Pipeline throughput rate
- New products completed/released to production last 12 months
- Cancelled projects and/or wasted spending last 12 months
- Percent R&D resources/investment devoted to new products (versus total of new products plus sustaining and administrative)
- Portfolio balance by project/development type (percent of each type of project: new platform/new market, new product, product upgrade, etc.)
- Percent of projects approved at each stage gate
- Number of ideas/proposed products in the pipeline or the investigation stage (prior to formal approval)

Organisation / Team

- Balanced team scorecard
- Percent project personnel receiving team building/team launch training/facilitation
- Average training hours per person per year or % of payroll cost for training annually
- IPT/PDT turnover rate or average IPT/PDT turnover rate
- Percent core team members physically collocated
- Staffing ratios (ratio of each discipline's headcount on project to number of design engineers)

Program Management

- Actual staffing (hours or headcount) vs. plan
- Personnel turnover rate
- % of milestone dates met
- Schedule performance
- Personnel ratios
- Cost performance
- Milestone or task completion vs. plan

- On-schedule task start rate
- Phase cycle time vs. plan
- Time-to-market or time-to-volume

Product

- Unit production cost / target cost
- Labor hours or labor hours / target labor hours
- Material cost or material cost / target material cost
- Product performance or product performance / target product performance or technical performance measures (e.g., power output, mileage, weight, power consumption, mileage, range, payload, sensitivity, noise, CPU frequency, etc.)
- Mean time between failures (MTBF)
- Mean time to repair (MTTR)
- System availability
- Number of parts or number of parts / number of parts for last generation product
- Defects per million opportunities or per unit
- Production yield
- Field failure rates or failure rates per unit of time or hours of operation
- Engineering changes after release by time period
- Design/build/test iterations
- Production ramp-up time Product ship date vs. announced ship date or planned ship date
- Product general availability (GA) date vs. announced GA date or planned GA date
- % of parts or part characteristics analyzed/simulated
- Net present value of cash outflows for development and commercialization and the inflows from sales
- Breakeven time (see above)
- Expected commercial value (This equals the net present value of product cash flows multiplied by the probability of commercial success minus the commercialization cost. This is multiplied by the probability of technical success minus the development costs)
- Percent of parts that can be recycled
- Percent of parts used in multiple products
- Average number of components per product

Technology

- Percent team members with full access to product data and product models
- CAD workstation ratio (CAD workstations / number of team members)
- Analysis/simulation intensity (analysis/simulation runs per model)
- Percent of team members with video-conferencing/desktop collaboration access/tools

APPENDIX 2: DAS Interviews

Interviews were held with the following departments:

- Support Engineering
- Production and Production Engineering
- Engineering
- Program managers
- Electrical design office (ECAD)
- Document Control Centre (DCC)
- Technical Publications
- Checkers
- Configuration Management
- Mechanical Design Office (MCAD)

Only one question was asked in the interview:

Please raise your concerns, issues, and/or problems that you experience in your area of responsibility?

The following table contains the answers (in the form of conversations) from the interviews, as well as the undesirable effect(s) that was identified from the conversations.

The interview conversations are tabulated with the undesirable effects that were identified.

Function	**Interview conversations**	**UDE**
Support Engineering	Support Engineering is not engaged early enough in the cycle to ensure the delivery of supportable products	Some requirements are incorporated too late in the product development process
	The data is not integrated. Each department has their own separate databases, thus the data is not visible to all stakeholders	Some data is stored in isolated databases
Support Engineering	Rework is done. Due to the limited knowledge of the different silos the quality of data from other departments is inconsistent e.g. data is not in the specified format or not meeting certain standards. Rework increases lead times.	Unnecessary rework is done Some requirements are incorporated too late in the product development process Quality of data from other departments is inconsistent
	If design for support does not take place then the costs increase in operations	Costs increase
Production and Production Engineering	Data pack changes causes unnecessary costs in production	Some changes are incorporated too late in the product development process Costs increase

Function	Interview conversations	UDE
Production and Production Engineering	Configuration Managers use different models for different projects	Configuration documents respond to the actual products
	In certain instances the Engineering Change Proposal process is not followed (i.e. red line drawings are used) because (1) it takes too long to get the black line drawing back from the Design Office and (2) there is not enough money/ hours to do the work	Often tasks takes longer than expected There are budget over-runs,
	Changes are implemented at the program manager's level but the impact of the decision on production was never verified. Changes that are implemented are immediately implemented in SAP but the Engineering Change Proposal only comes much later	There are too many changes, Some changes negatively impact the work of other departments
	The formal Engineering Change Proposal process takes too long	Often tasks takes longer than expected ECP takes too long Some changes negatively impact the work of other departments
	Many changes are made during the production phase of the product lifecycle	Too many changes are initiated in production
	The data pack takes too long to be completed or updated.	Necessary things are not available on time (information, specs, designs, etc.),

Function	Interview conversations	UDE
Production and Production Engineering	Production often waits for materials	Raw materials/parts are not always available when needed Too many changes are initiated in production
	Currently the engineers build the prototype and then industrialization only happens during the production phase. The engineers make small changes while building the prototype and do not document it thus production actually receives an incomplete data pack. As a result production takes much longer than necessary – extra ECP's are generated.	All product data is not thoroughly documented Necessary things are not available on time (information, specs, designs, etc.), Configuration documents respond to the actual products Some requirements are incorporated too late in the product development process
	ECP lead time is longer than a month.	ECP lead time is too long
	The procurement process focuses on decreasing costs; this leads to parts that are scrapped by production due to quality reasons.	In some cases sub standard raw material components are purchased

Function	**Interview conversations**	**UDE**
Production and Production Engineering	Each department optimizes locally.	
	Quality forms a part of procurement thus production must contract their services.	Available resources cannot be used
	If there are not enough man-hours available for the project then resources will not complete the project. Resources must share equipment; having to wait for the equipment to become available increases lead times.	Resources are not always available when needed
Engineering	Currently material takes between 3 days to 6 months to be delivered	Materials are not available when needed
	Due to product changes the wrong material is ordered and extra costs are thus incurred	There are too many changes,(wrong materials are ordered; cost increase)
	ECP process takes too long	ECP process takes too long
	The support services (e.g. procurement, HR and IT) are not focused on getting the work through the department within the shortest lead time Due to support processes that takes too long the engineering department only makes use of their services when absolutely necessary.	Procurement takes too long

Function	**Interview conversations**	**UDE**
Program managers	Program managers choose to contract outside suppliers because they are not late and are in some cases cheaper than in-house services	Too often promised due dates are not met and there are budget over-runs,
	Programs share engineering resources	Resources are not always available when needed Multitasking
	It takes too long to update small changes in CAD	Often tasks take longer than expected
	The drawing office takes too long to complete their tasks	Resources are not always available when needed
	Procurement takes too long	Procurement takes too long
	Significant changes are made throughout the project and not just during the development phase	There are too many changes Too much rework is done
DCC	Legacy data is stored in containers and other remote locations and thus takes too long to retrieve	Legacy data takes too long to retrieve
	Each Configuration Manager has his own way of doing documents	Configuration management is not done according to a standard process
Checker	Iteration between checker and draftsman may be up to three times. This is caused by checkers that do not specify changes thoroughly and one change that in turn causes something else to change	Unnecessary rework is done

Function	**Interview conversations**	**UDE**
Configuration Management	Expectation for PDMLink: The PDMLink System will force the Configuration Managers to follow the preferred Configuration management process. Currently the CM Managers do not use a uniform CM process	Configuration management is not done according to a standard process
	CM managers do not estimate the costs and time it takes per task thus the whole project status is not estimated correctly	Often tasks take longer than planned There are budget over-runs,
	30% of meetings held to approve a design change is unnecessary but currently there is no formal procedure to accommodate 'simple' change requests	The system cannot accommodate 'simple' change requests
	With new developments the engineers tend to take too long with the development phase due to multitasking and admiration for sophistication. Then the drawing office is under pressure to deliver data pack and when under pressure it is more likely that faults will occur.	Necessary things are not available on time (information, specs, designs, etc.), or Often the input is not complete Often tasks take longer than planned There is a lot of multitasking There is a lot of unnecessary rework
	With development projects: production has already started building the model /prototype before the specifications has been approved. This is a result of the project due date that is under pressure. In such a case the first priority is to complete the hardware and thereafter ensure that the CM process is up to date.	Design changes are made after the prototype/manufacturing has started

Function	Interview conversations	UDE
Configuration Management	It is difficult to get engineers to complete the support documents for a product when the product has been delivered. This is due the fact that the engineers' priorities move to new projects and most of the time they do not have any man hours left for the previous project to complete the documentation and administration of that project. New projects are more interesting or more of a challenge thus researchers do not finish the previous project's documentation.	Support documents are not finished when required Configuration documents respond to the actual products
	The inputs of a process are not always defined completely e.g. the contract does not always specify or define all the needs/requirements of the client.	Often tasks takes longer than planned There are budget over-runs Too often promised due dates are not met
	Limited resources; Multitasking; The amount of work necessary is underestimated.	Multitasking is a problem Often tasks take longer than planned
	Part and/or material obsolescence is a problem	There is a lot of unnecessary rework
	Sometimes decisions are made based on assumptions The departments work very much in isolation	Some decisions are made on assumptions

Function	Interview conversations	UDE
Mechanical Design Office	Capacity problems are a reality	Often resources are not available when needed
	The design office spends 30% of their time on administrative tasks lsuch as 'chasing' signatures and uploading PDF's into SAP	30% of Design offices time is used for admin tasks (chase signatures; SAP upload; PDF's)
	The checkers check and release parts for production without having checked the assembly as a whole – parts are checked for manufacturability and not assemblies for form, fit and function.	Quality decreases There is too much rework
	The amount of time necessary to do the detail design and to generate the first data pack often takes longer than expected.	Often tasks takes longer than expected
	The inputs for a process are not always thoroughly defined. Thus drawings are done without the complete specifications	Necessary things are not available on time (information, specs, designs, etc.), or Often the input is not complete
	The department managers are not consulted with the allocation of man hours/resources for individual projects.	Often resources are not available when needed
	Program managers define the priorities but it is not always known throughout the project team. This leads to multitasking.	There are fights about priorities between tasks or Often the priorities of tasks change
	Every Configuration Manager has his own way of interpreting the CM processes which leads to unnecessary rework	There is too much rework Configuration management is not done according to a standard process

APPENDIX 3: PDS Assessment

The Product Development System (PDS) Assessment identified the AS-IS product development situation at DAS. The TO-BE column represents the proposed best practices to be applied with the implementation of PTC's product development suite.

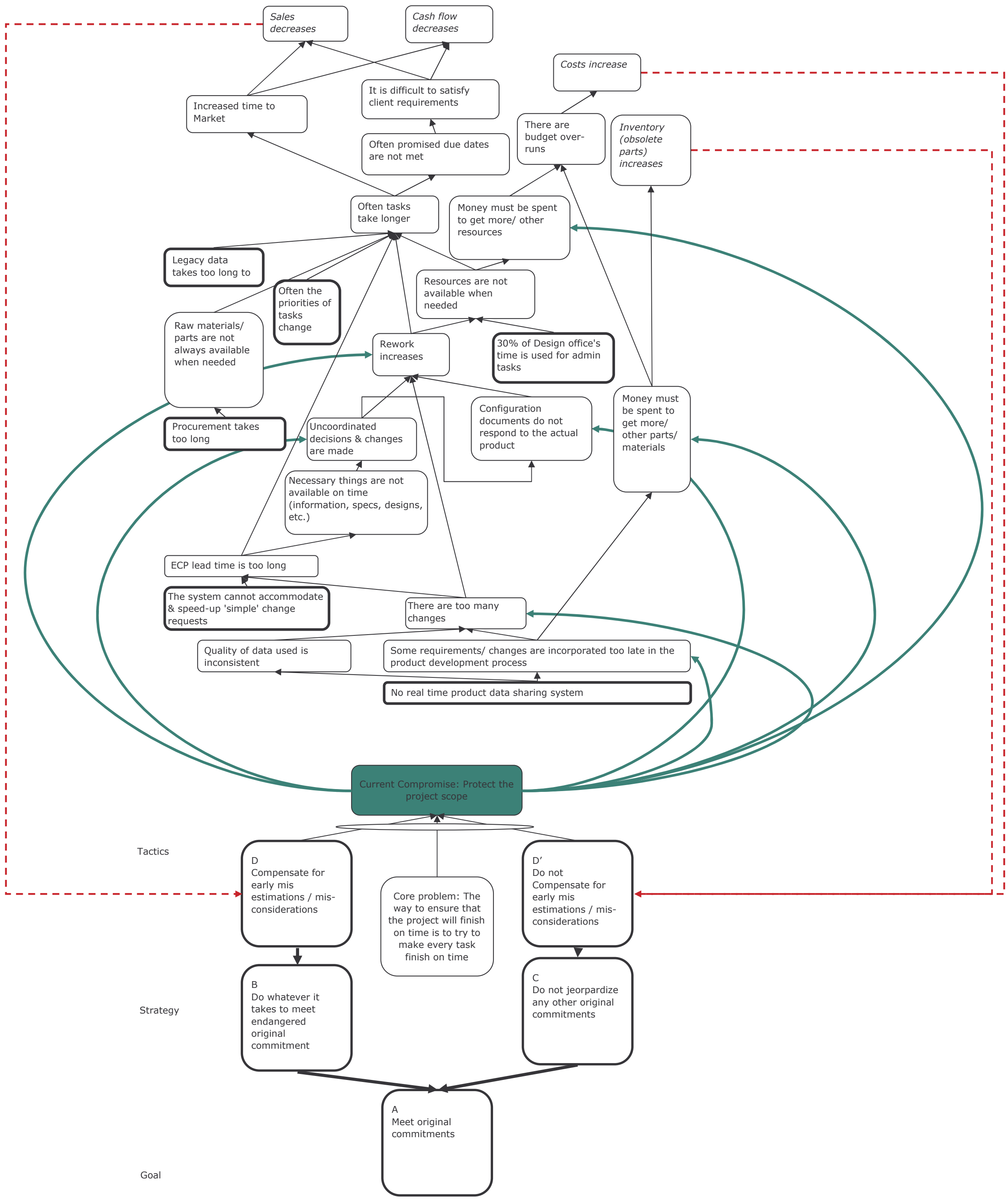
CAPABILITIES	AS IS	TO BE
Digital Product Definition Environment	3D CAD, model is the master	Complete digital product model
Digital Mock-ups	Mostly digital, some physical mockups	100% digital mock-ups
Simulation and Optimization – data conversion from modeling application to simulation application	Data converted/ported thru custom/std interfaces	No data converted/ported
Simulation and Optimization – timing	After design ~ Concurrently with design	Concurrently with design
Generation of Downstream Deliverables	3-D master model used to generate engineering drawings and verify assembly fits only ~ Limited generation of downstream deliverables from the 3-D master model	Product is completely defined electronically leveraging the 3-D master model, including all downstream deliverables: BOM, production drawings, tooling, toolpaths, digital prototypes, simulation reports, technical publications, production plans …
Individual Modeling and Working Methods Skills Development	Skills routinely evaluated, sporadically enhanced ~ Skills routinely evaluated, and routinely enhanced for some individuals	Skills routinely evaluated, and routinely enhanced for all individuals

CAPABILITIES	AS IS	TO BE
Modular Product Architecture Management	We have a system engineering function that is responsible for definition and ownership of the product architecture ~ A cross-functional team (production, marketing, engineering, etc) is responsible for defining our product's architecture with focus on strategic direction	A cross-functional team (production, marketing, engineering, etc) is responsible for defining our product's architecture with focus on strategic direction and a system engineering function is assigned to own the architecture during product development
Modular Product Architecture Definition	A process exists to define core modules but no attention is given to module interfaces ~ A process exists to define core modules and module interfaces based on engineering requirements	A process exists to define core modules and module interfaces aligned to business strategy
Design for Manufacturability	Goals are set for design for manufacturability enabled by design review workshops	Goals are set for design for manufacturability enabled by design review workshops along with measurement and improvement tracking
Design for Quality	Quality goals are set and enabled by design review workshops	Quality goals are set and enabled by design review workshops along with measurement and improvement tracking
Design for Serviceability	Designers expected to consider serviceability in designs but service costs are still high ~ Service goals are set and serviceability is a key factor in design review workshops	Service goals are set and serviceability is a key factor in design review workshops along with measurement and improvement tracking
Product Data Retrieval Time	Seconds/minutes - server based	Seconds - PLM search by attribute
Product Data Storage Management	Multiple vaults, unconnected	Multiple Vaults, Single Logical Repository
Product Data Electronically Managed	75% of product data in electronic form	100% of product data in electronic form

CAPABILITIES	AS IS	TO BE
Check- in and Checkout	Electronic storage of documents in multiple databases with inconsistent check-in and check-out procedures ~ Electronic storage of documents in multiple databases with common check-in and check-out procedures	Electronic storage of all documents in a central vault with controlled check-in and check-out procedures
Product Data Access Security	User Login only	Object level
Visualization of Product Information / Data	Application-independent visualization, no mark-up capability	Application-independent visualization by all internal/external project team members with full mark-up capabilities
Design/Part Reuse	Project ~ departmental level reuse , some computer search capability	Enterprise level reuse, robust computer search capability
Engineering Change - Process	Mix of electronic workflow and manual process steps for initiation, review, markup, approval, distribution, reports and notification	Full electronic workflow for initiation, review, approval, distribution, reports and notification
Engineering Change – Process Scope	Electronic workflow, Engineer Dept only, disconnected from other depts.	Enterprise wide scope, including partners
Engineering Change – Impact Assessment Scope	Assessment done at Engineering Dept level	Assessment done throughout the enterprise (includes partners)
Engineering Change – Impact Assessment Process	Assessment is an even mix of manual and electronic tools	Fully electronic assessment of change impact
Engineering Change – Monitoring and Reports	Periodic monitoring and generation of reports	Online dashboards available to show change management trends and cycle time
Bill of Material	One BOM management system, multiple views (as-designed, as-mfg, etc.)	One BOM system, multiple views, integrated with the Engr Change system

CAPABILITIES	AS IS	TO BE
Configuration Management Process	Electronic configuration system that dictates a new part number for every change	Full electronic configuration management system that supports enforcement of configuration policies
Part Traceability	Trace back all parts, mix of manual and electronic tools	Trace back all parts, electronically
Product Development Information Sharing	Shared effectively within engineering, not among manufacturing, sourcing, sales, marketing, etc.	Shared effectively across the extended enterprise (customers, suppliers, partners)
Real-time Design Collaboration Technology	Basic technology in place enabling collaboration by phone, fax, or email	All of the above plus Peer-to-peer design conferencing facilitating real-time collaboration
Collaboration System Management	Collaboration systems evolve from the collaboration parties determining the best way to collaborate and no process exists for defining, continuously improving, and maintaining our ability to collaborate	A formal process (with ownership) exists to defining our collaboration needs, design a supporting system, and continuously improve that system
Collaboration Functions	We collaborate effectively within and between internal functional groups only	We collaborate effectively internally and with all external functions (customers, partners, suppliers)
Product Design Reviews - Scope	Design reviews conducted informally with two of the following functions (manufacturing, customers, suppliers, partners, other)	Design reviews conducted informally with all functions influencing or benefiting from a product design
Product Design Reviews - Process	Design reviews follow a structured review/approval process that involves problem solving and action setting activities but use non-standard review tools requiring a co-located review team.	Design reviews follow a structured review/approval process that involves problem solving and action setting activities and leverages standard electronic review tools to enable a distributed review team.
Co-Development Projects Satisfaction / Results	Somewhat unsatisfied ~ neutral	Very satisfied

CAPABILITIES	**AS IS**	**TO BE**
Data Reentry during release to manufacturing process	Data reentered 2 times	Data not reentered
Product Information Legacy Systems	3-5 legacy systems	Single system for all product information
ERP Interface	Proprietary, custom unidirectional interface	Out-of-the-box seamless, bi-directional interface



The core conflict of DAS

DAS Future Reality Tree

The CRT of the current DAS PDMLink implementation approach