Alignment of Planning and Execution phases within Denel Dynamics

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Executive Summary

Operations Management encompasses a wide variety of activities. At *Denel Dynamics* the most important of these is the *Planning Phase* which directs the flow of production and is thus critical to the success of the company.

The problem is that a significant “gap” exists between this planning phase and the actual execution of the various projects. This seems to be mainly because of the instability present in the complex environment of armament production. This instability most often leads to projects exceeding their initial time lines and thus accruing additional costs in the form of penalties, rework and *frequent rescheduling*.

The focus of the study lies in examining the causes, identifying the problem areas (between planning and execution) and the ultimate revitalization of its current scheduling methodology, traditional MRP.

As will be illustrated in the project, conventional MRP procedures have little benefit to modern production’s bottom line and more innovative scheduling is needed which will present itself in the form of *Critical Chain Scheduling.*

Because of the specialized nature of Denel Dynamics’ market, several factors will be taken into account, such as the political environment, economic climate, supply chain visibility, logistical factors etc. As these factors do not carry equal weight in influence they will only be discussed briefly.

The anticipated outcome will be an improvement in the *Planning phase* through improved *scheduling practices* in order to ensure better *execution* in thislow volume, high complexity production environment to ensure the continuous success of South Africa’s missile and UAV producer, Denel Dynamics.

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1 Introduction and Background

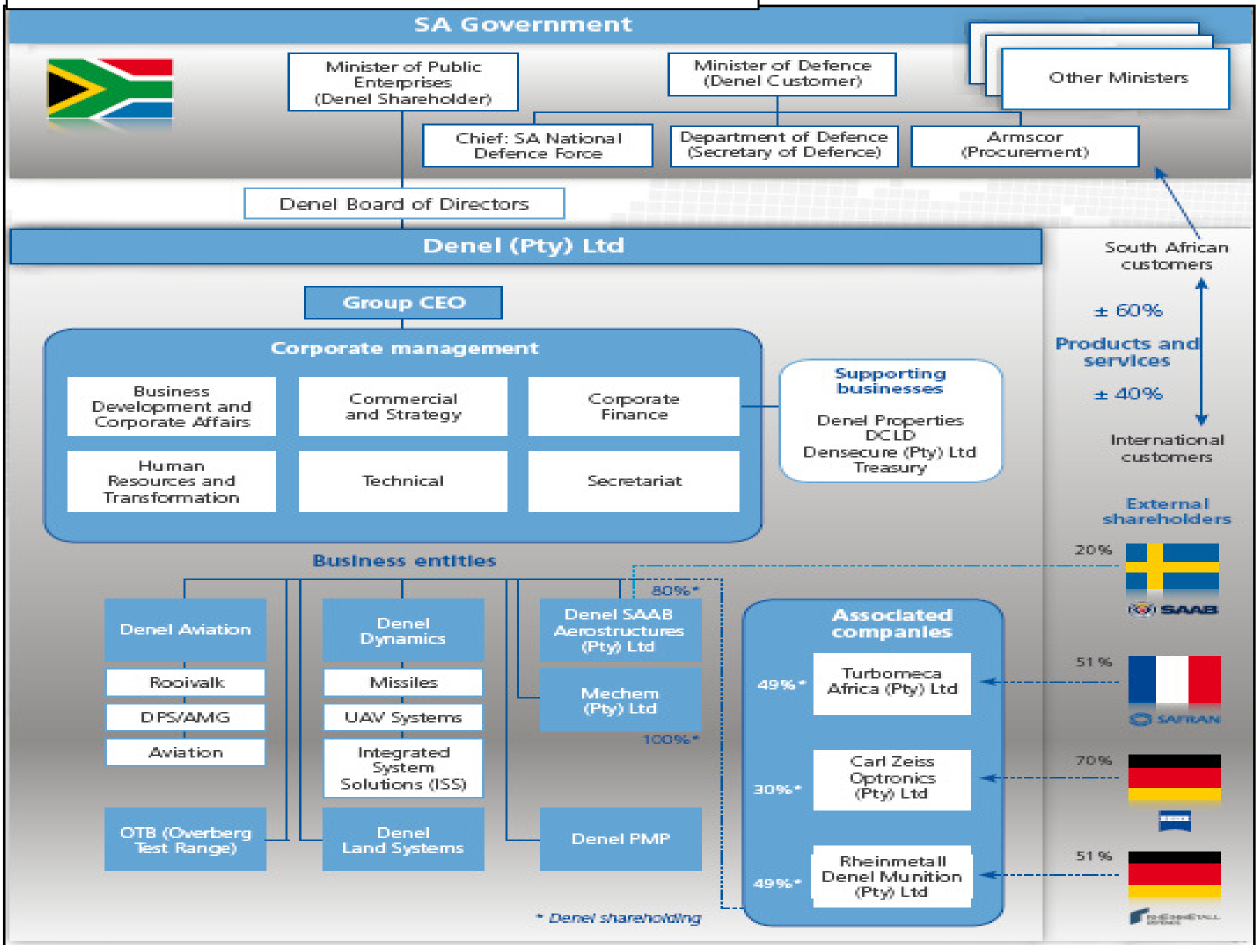
1.1 Denel in General

Denel was founded as South Africa's main producer and supplier of weaponry. Currently, Denel incorporates various international affiliations and consists of eight separate business entities each specializing in their own field. These eight entities are as follows:*(Denel)*

- **Denel Aviation**
- **Denel Saab Aero structures**
- **Denel Land Systems**
- **Denel Dynamics**
- **Denel Properties**
- **Denel PMP**
- **Mechem**
- **OTB (Overberg Test Range)**

1.2 Denel Organizational Structure

Figure 1: Denel Organizational Structure: Denel 2009



1.3 Denel Dynamics

Although a number of Denel branches will be researched for purposes of comparison and insight, the main focus lies with ***Denel Dynamics***, manufacturer of *tactical missiles, precision-guided weapons and unmanned aerial vehicles (UAVs).*

Situated in Irene, Pretoria, Denel Dynamics employs approximately 800 people, 70% of which is highly technically qualified. Denel Dynamics provides for both South Africa and internationally, boasting various affiliations with countries such as Sweden, Germany and Brazil.*(Denel Dynamics)*

1.4 Introduction

Within Denel Dynamics exists a variety of departments, each in command of its designated assignment. From the Planning office through to Operations Management, the personnel are responsible for ensuring satisfactory production planning and *continued supervision* throughout the project's life cycle.

Complications do however arise, and should the original production plan not contain sufficient detail on how to deal with these complications, severe time and cost penalties can be incurred.

Consequently, in order to avoid such penalties and/or delays and to better manage various projects, sufficient study is needed in an attempt to determine the appropriate planning strategy and the various contingency plans associated with it so as to better manage and mitigate these events.

2 Project Aim

The project of *Aligning Planning and Execution* in Denel Dynamics' Operations Management division has both strategic and academic aims:

To gain a better understanding of the planning phase of Denel Dynamics' ventures in order to align the planning phase and the execution phase in missile production through improved scheduling, and continuous management.

Impacting factors must be examined in order to gain a better understanding and to identify any gaps. An endeavor to achieve **better lead times** for the various projects must be made so as to develop better client relations, improve profit margins and most important: *to be able to mitigate the possible unforeseen circumstances arising during the course of said project(s) which may put the applicable project(s) in jeopardy.*

3 Project Scope

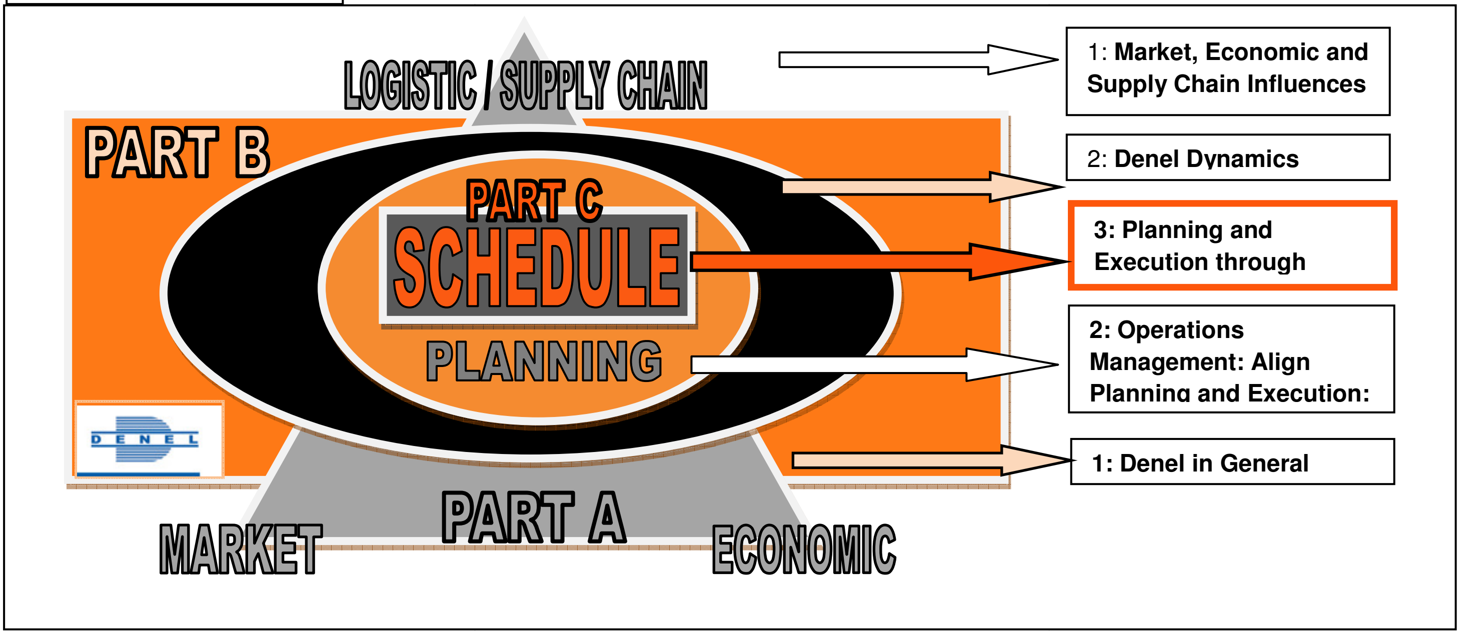
As the detailed planning phase of Denel Dynamics is directed by the Operations Management division (which includes the majority of Industrial engineers at Denel Dynamics) the focal point of the project will revolve around this particular department.

Due to the complexity and somewhat abstractness of the problem, a variety of techniques will be investigated in order to apply the appropriate method in anattempt to enhance Denel Dynamics' current planning modus operandi. Thus, a probe into the environment of Denel Dynamics' product market will also need to be done. Since their product market is of an international nature, factors influencing this market (including the armament market itself, economic climate, supply chain and logistics) will also be taken into account where relevant.

*The main focus of the project will lie with **missile production**. As the production of missiles and UAVs respectively are very diverse in nature, they follow separate paths throughout both Denel's planning and its production phases and should consequently be managed separately.*

The following figure illustrates the project boundaries in diagrammatical form. The key focus is in the center point of the diagram with the more holistic view and environment encompassing this focal point of planning indicated on the periphery of the diagram:

Figure 2: Scope Diagram



The Project has been broken into 4 different parts:

1. **Part A: Aerospace/Defense & Denel Overview:** Provides insight into the industry with regards to market, economic and Supply Chain influences and trends.
2. **Part B: Denel: Current Procedures and Problems:** Analysis of the environment in which Denel Dynamics functions, as well as descriptions of their current procedures and the problems they currently face.
3. **Part C: Solution: Aligning Planning and Execution:** Demonstrates that by implementing new and innovative scheduling methodologies, various problem areas can be sufficiently addressed
4. **Part D: Implementation, Results and Benefits:** The last section illustrates implementation, provides measurable results and anticipated outcomes as well as identifies potential benefits and possible challenges.

PART A: Aerospace/Defense & Denel Overview

4 Industry Analysis

4.1 Overview

The arms industry of South Africa was established when Britain as the former colonial power, decentralized its ammunition and armaments production in the prelude to World War II. In an attempt to re-establish South Africa in the international community it was previously isolated from, the South African National Conventional Arms control Committee (NCACC) issued export permits for arms to the value of R5.9 Billion for approximately 88 various countries.(*Denel)*

The face of production planning (especially in weapons manufacturing) has changed radically over the years and the once sufficient annual operating plan no longer suffices in the dynamic global market most companies interact in. With volatile demand and global supply chains, disruptions in supply chains have become commonplace and significant gaps have surfaced in the managing of the planning phase.*(Miles, 2009)*

The world of Armament transactions, procurement and export is an especially complex one which must be scrupulously examined if any attempt is to be made at an inclusive strategy to align planning and execution

4.2 Market Research

As the main focus lies with Denel Dynamics as manufacturer of Missiles and UAVs, adequate information regarding the market will be taken into in order to place the problem and ultimate design solution in proper context. In order to ensure that the alignment of the planning phase with production is done comprehensively, contributing factors (such as frequency of orders etc) is taken into account by analyzing the Global Missile and UAV market as well as the existing trends and their influencing factors.Analysis of the pertinent market trends is the first step in realizing subsequent strategy implementation success.

4.2.1 Missiles

The production and procurement of missiles as a global market is growing regardless of current economic downturns. As political circumstances shift and change, various new reasons for procuring such weapons arise.

Teal Group Analysts is a supplier of independent aerospace and defense industry market analysis currently tracks and provides data on all 156 individual missiles, UAV and smart munitions programs. Their forecast in 2006 was that the *global* missile market will continue its growth pattern over the next decade and more.*(Anon. Teal Group, 2006)*

One reason for the growth in the missile market is (surprisingly) the current economic conditions prevailing throughout the world. The reason for this is simply that *it is more cost effective to add sophisticated weaponry (and specifically missiles) to existing (old) aircrafts, ships etc, than it is to purchase a new aircraft or other military vehicle.* The above mentioned forecast included a predicted value of *600,000* missiles totaling *$103.7 Billion* during the 2006 to 2015 decade.

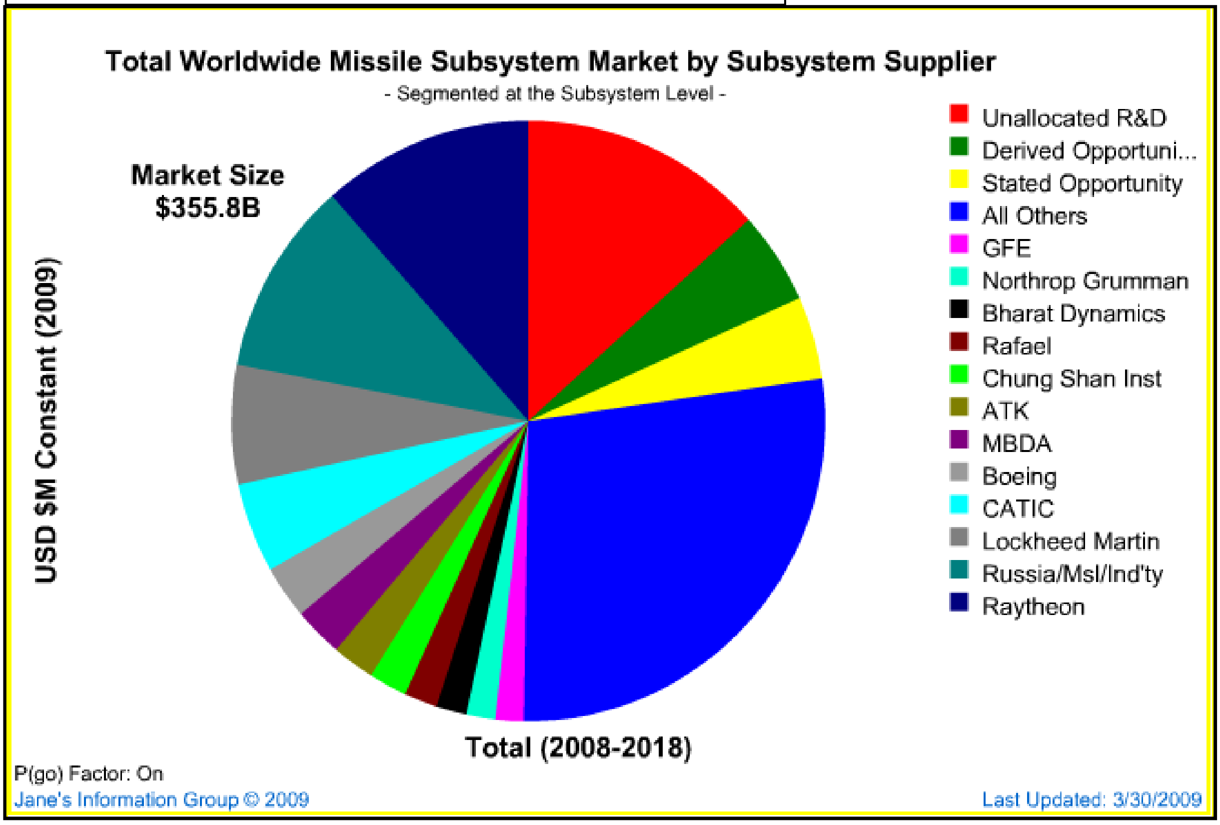
According to *Forecast international, Inc*., a leading provider of market intelligence and analysis in aerospace and military economics, this trend is expected to continue into 2018, bringing air defense missiles (largest sector of the market) to an expected $27bn in value. *(Forecast International)* ***Table 1*** depicts the projected values for 2015 for some of the missile categories in their order of dominance of the global missile market.

Table 1: Projected values for 2015 for missile categories
in order of dominance of the global missile market. *(Teal Group)*

Missile Category	Monetary Value ($bn)	Percentage of Market	Approx. no of units
Air Defense	28.9	27.9 %	48,194
Surface to Air	19.9	19.2 %	41,610
UAVs	13.2	12.7 %	17,976
Anti – tank	12.0	11.6 %	140,759
Surface to surface	11.2	10.8 %	6,206
Air to Air	9.6	9.6 %	41,470
Anti Ship	8.5	8.2 %	5,050

Below is a graph presented by *Jane's Defense market information group* outlining the predicted market segments of the various subsystem suppliers for the period of 2008 to 2018. *(Jane's Defense Information Group)*

Figure 3: Total Worldwide Subsystem Market by subsystem Supplier for 2018: Jane's Information Group



4.2.2 UAVs (Unmanned Arial Vehicles)

Although the main focus of the project will be on the production of missiles, a brief insight into UAVs is needed to provide a holistic insight into the multifaceted environment Denel Dynamics encompasses.

Over recent years, the growth rate of UAVs has started to decline, yet UAVs continue to be the most prominent and actively growing sector in the world aerospace industry. The 2010 market study by *Teal Group* indicates that expenditures towards UAVs will be twice its current value by the end of the decade.

This staggering growth in value will result in that of $80 billion in ten years' time with annual spending increasing from $4.9 billion to $11.5 billion.

The increasing importance of UAVs lies in their significant role in intelligence, surveillance and reconnaissance (ISR). The United States of America has been identified as the leading procurer and is expected to acquire approximately 58% of all UAVs in the next decade. Europe signifies the second largest market (by the use of –among others – the UK's Hermes-derived WK450 Watch keeper) followed closely by Asia Pacific.*(Anon, TMC News 2010)*

Table 2: Market indications for UAVs as predicted by various sources

Source	Date	Forecast	Uses	Comments
Department of Defense	FY 2001 budget	Strike force to be 1/3 UAVs by 2010	Military	Airframe and avionics
Teal Group	Dec 2002	Market to double by 2014	Military, science, homeland security	Airframe and avionics
Frost and Sullivan	Oct 2003	5.5B EUR by 2012	Military, science, homeland security	Airframe and avionics
Forecast Int'l	Oct 2003	$10.6B by 2013 Massive growth 2010	Military, science, homeland security	Airframe and avionics
Teal Group	Aug 2004	$4.5B/yr by 2014	Military, science, homeland security	Airframe and avionics

4.3 Economic Influences

4.3.1 War and Peace Cycles

The recurrent cycles of warfare are strongly coincident with those of Kondratieff (economic) cycles.

In an attempt to forecast sales (*see MPS in section 5.2.2*) and consequently production, a pattern can be identified in the demand for weaponry – which relates directly to the products manufactured by Denel Dynamics.

From history (hind casting) we have learnt that the minimum interval between Great Power Wars is 34 years with the correlating maximum being 99 and the average approximately 50 years. War cycles correspond almost exactly to "*Kondratieff Waves"* developed by a Soviet economist, Nikolai Kondratiev, which depicts the current capitalist economy in cycles of approximately 50 years. The link for both these cycles may lie in the need for innovation and necessity breeding invention. Civil violence shows a comparable pattern with a mean frequency of 60 years. The war cycle has however increased in length over the past five centuries as the wars themselves have shortened, but their severity has increased tremendously.*(Hoskins, 1985; Krus &Webb, 1992)*

Usury, or interest, also has an influence on both a civil and international scale. Every financial upheaval, major war, economic depression and famine can be linked to the influence of usury banking. So called "hot wars" are characteristically fought near the decline of the War/Peace cycle and are waged only as a desperation measure to stimulate an economy suffering from the effects of deflation as a consequence of usury.(*Droke, 2002)*

Numerous studies have been done with centuries' worth of data in determining these cycles. The graph shown in ***figure 4:****(Col. Smith, 2008)*shows the frequency of Global Conflicts over approximately 20 years.

Figure 4: Global Conflicts 1990 – 2008. Col. Smith. 2008

*Edward R Dewey, (1970)*from the foundation for the study of Cycles, uses what he calls the ***systematic period Reconnaissance or SPR*** (similar to *harmonic analysis)* to analyze periods where cycles may occur as indicated by such reconnaissance.
Through his studies, a list of Cycles in the index of International War Battles has been compiled as follows:*(Dewey, 1970:121-158)*

Table 3: A list of cycles discovered to date in the Index of International War Battles. *Dewey, 1970*

Period of Cycle (Years)	**Time Span over which observed**	**Date of an Ideal Crest**	**Amplitude % over trend**	**Notes**
142	1 – 1950 AD	1950	78	
57	1750 – 1943 AD	1975	151	
21.98	556 BC – 1900 AD	1962.34	12	
17.71	600 BC – 1957 AD	1971.68	15.0	International and Civil combined
12.34	563 BC – 1943 AD	1943.17	24.7	Present in alternate 86.4 year blocks
11.24	529 BC – 1900 AD	1970.7	8.65	
9.59	562 – 1957 AD	1972.6	23.8	Present in alternate 86.4 year blocks
5.98	600 BC – 1957 AD	1967.6	2	
5.5	1750 – 1943 AD			Details not determined

4.3.2 Past, Present, Future

With the volatile economic market that made its impact felt from middle 2007, the first question to ask when attempting to predict sales and/or order frequency and seasonal/cyclical influences, is how the economic environment will impact the market.

Contrary to expectation, the arms race has picked up the pace - especially in South-east Asia and South America. A very current example of this is Brazil's interested in the Denel-manufactured A-Darter SRAAM Missile. Because of the sale of Germany's armored vehicles, they have also reported increased exports by more than 100%. Other examples of increased procurement and/or sales are Venezuela, Saudi Arabia, Britain and the top exporter, the US. Malaysia also falls into this group and also has newly signed contracts regarding turrets for their recently procured personnel carriers.*(Anon TMC News,2010)*

History shows the same phenomenon of the weapons industry remaining stable or even growing despite economic crises, or indeed, at times, because of it.

One such example is the US Stock Market Crash of 1929 and the following Great Depression 1931 that is seen as a mechanism that precipitated the entry of the US government into the Second World War. Similarly, economic differences triggered the US Civil war of 1861 to 1865. (*Oppapers,2006*). Developing countries are the forerunners in weapons procurement with the following statistics gathered during the 2001 to 2008 period:

Figure 5: Arms Sales agreements by Developing Nation: Grimmet, 2009

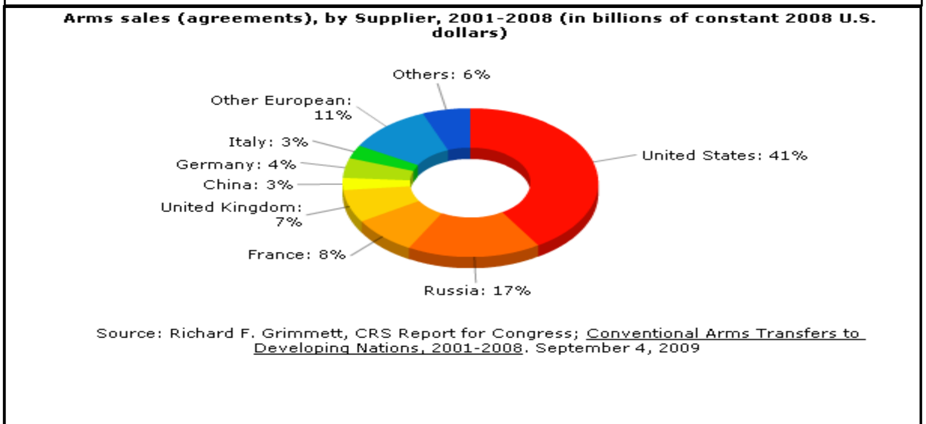
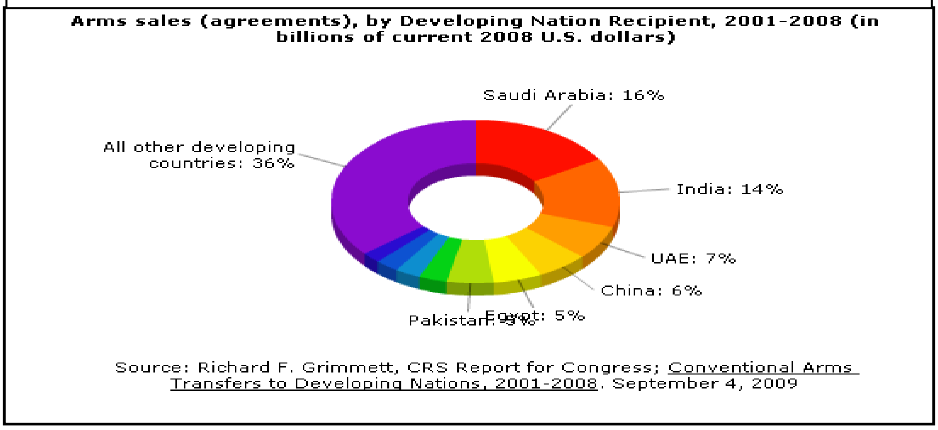


Figure 6: Arms Sales agreements by Supplier: Grimmet, 2009



Economic hardship can potentially drive desperation for resources, manpower, tactical infrastructures and regulation and/or attainment of commodities. This in turn leads to nations rearming either for offensive or defensive purposes.

The world is in a seemingly constant need for weapons, be it for reconnaissance, intelligence, because of fear or dominance and a natural assumption from both present and historical information is that this trend will continue regardless of what the economic future holds.

4.4 Logistic / Supply Chain factors

4.4.1 Precedent study

*Miles, 2009,*discusses the importance of *continuous alignment of Demand and Supply in order to manage the gap between planning and execution* within any manufacturing environment. He notes that in the past, specific **buffers** were implemented as a **"just-in-case"** practice.*(See buffer management section 8.3.2).*These precautions are however no longer viable as an adequate strategy within an extremely cost-aware environment with lean supply chains and decreased inventory levels and a *continuous approach* is needed.

Increasing complexity and emphasis on cost reduction within military contracts is forcing companies to revisit their internal supply chain strategy as well as the nature of the subsequent relationship(s) with their contractors. *Various armament manufacturers have recently revamped their respective supply chains – either as a preparatory measure or as a response to complexities encountered in their current processes.*

One such example is Lockheed Martin. Lockheed has changed their supply chain system by choosing to rely on contractors to provide parts (often directly as produced) with only minimal customization (if any) rather than custom building parts for every system – *thus reducing vertical integration.* The US Department of Defense opted to follow a similar strategy to Lockheed. They encountered a problem similar to one experienced within Denel Dynamics, namely rapidly advancing technology competing with comparatively sluggish production plans.

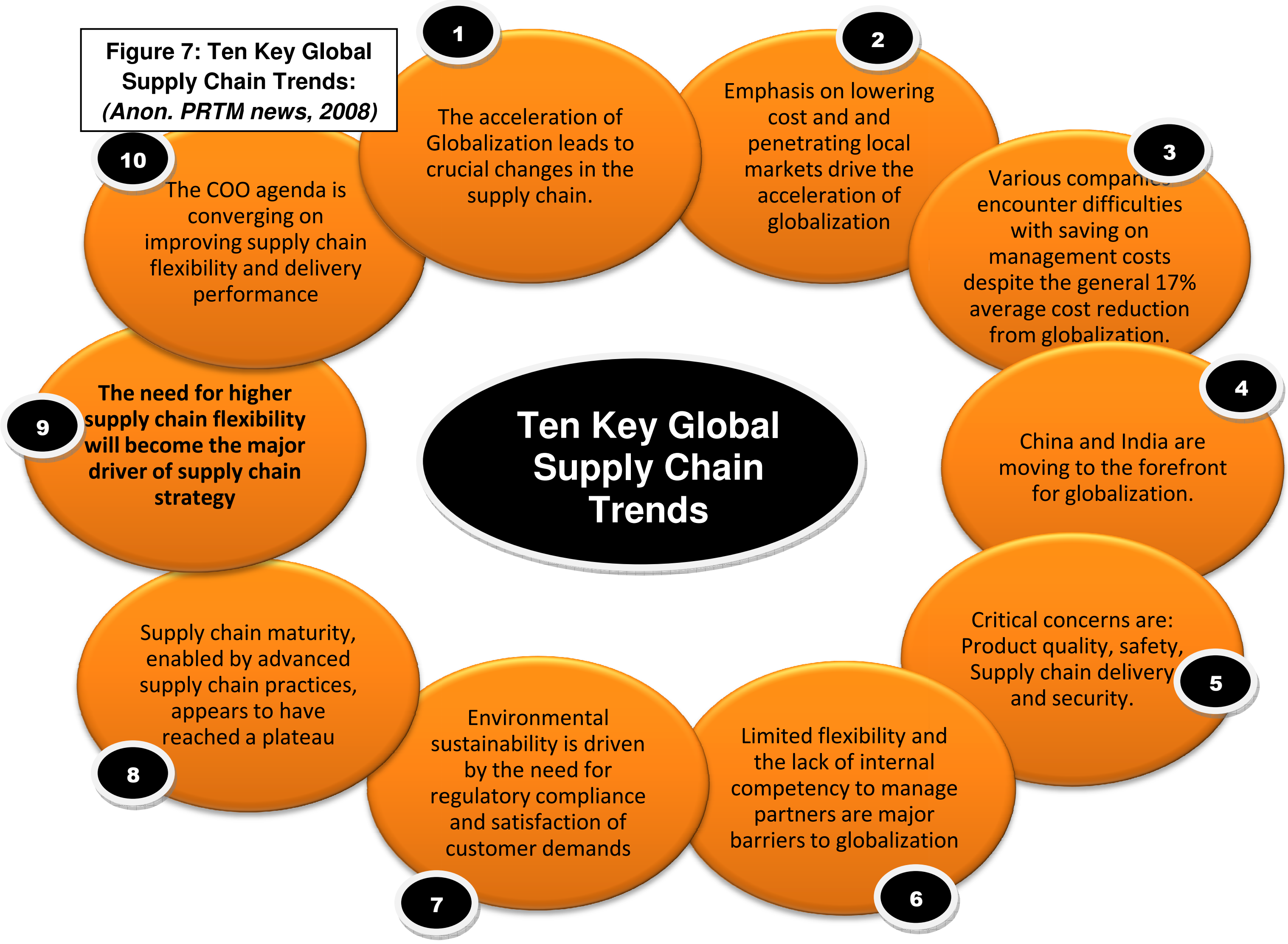
Military procurement processes seldom keep up with technological advances, and the development thereof should thus also be taken into account. *(Fogarty, 2006)*

4.4.2 Trends

Supply Chain Management (SCM) has undergone dramatic evolution since its inception. As markets become increasingly competitive, new emphasis is placed on ensuring that these **Supply Chain strategies remain dynamic** in order to keep up with industry demands.

PRTM Management Consulting, 2008 identifies the ten key trends for the future of Supply Chain Management. ***(Figure 7)*** Note number 9.

Figure 7: Ten Key Global Supply Chain Trends:
(Anon. PRTM news, 2008)



As part of rapid response capabilities, the future trends of supply chain management must be kept in mind when attempting to provide a sufficiently agile and responsive production plan to continually manage manufacturing.

The first step for Supply Chain Managers to take will be to convert their existing supply chain from *tactical level* to a *strategic one.* To clarify, *strategy* refers to a course of action or initiative through which an organization may reach specific goals or objectives. *Tactics*, on the other hand, refers to operational aspects that are required to support a strategy.
(Bardi, Coyle & Langley, 2003)

The Massachusetts Institute of Technology (MIT) has systematized the process in order to assist practitioners to expand their understanding of their supply chain strategy in a step by step manner. This includes evaluation in terms of sufficiency, coverage and alignment and improving the SC to better serve the firm's objectives.

The key objectives of their project are as follows:

- To gain a more in-depth understanding of the existing Supply Chain Strategy and other practical strategies it encompasses.
- The performance of activities will be evaluated in order to assess the current supply chain strategy in terms of their strengths and weaknesses.
- Concrete recommendations on how to improve the coverage and alignment of the existing supply chain strategy *(MIT)*

It is imperative that Global companies (such as Denel Dynamics) familiarize themselves in current and future developments in Supply Chain Management in order to ensure Rapid Response Capabilities in an ever-changing market. *(Massachusetts Institute of Technology, Supply Chain Project, 2006)*

PART B: Denel: Current Procedures & Problems

5 Denel: Planning and Production

Due to the sensitive nature of information in the weapons manufacturing industry, along with numerous confidentiality clauses, exact data may not always be recorded. The theories, formulations and calculations will however be based on the data received and will remain true to the nature of armament production relevant to Denel Dynamics.

5.1 Manufacturing Approaches

The Classification of Denel Dynamics' manufacturing relies strongly on the type of contract/order awarded. Of the various manufacturing strategies available, Denel Dynamics focuses on **ETO (Engineer to Order)** and **MTO (Make to Order).** This is due to the high level of complexity of their products, the customization, the extensive design environment and the fact that these are indeed high cost items.

5.1.1 Pull System

Manufacturing is predominantly modeled on the Japanese "pull-system" or Kanban, where production is triggered by customer demand. The concept results in a leaner system where no excess stock is kept from either work in progress (WIP) or finished products because the system only produces exactly what must be delivered.

5.1.2 MTO – Make To Order

As mentioned in the previous section, the high value and complexity of the product is to be taken into account when deciding on a manufacturing strategy. Pull-type systems are characterized by the assembly industry and its types include MTO (Make to Order), ETO (Engineer to Order), BTO (Build to Order), and ATO (Assemble to Order). Denel Dynamics mainly incorporates both MTO and ETO depending on the type of contract received.

The successful implementation of Make to Order strategy relies on receiving the order prior to manufacturing and ensures that no product is manufactured when there is no demand for it. If the client is willing to wait, the favorable approach is to *plan for variation before* commencing with manufacturing – this is however not always done.

The product is always of high value and its complexity filters through the BOM (Bill of Materials) and no part can be produced as 'standard' or in batches. This in turn, annuls the option of ATO (Assemble to Order) where various parts are kept in stock and assembly (production) commences as triggered by customer demand. Although all missiles have genetic traits and sometimes a few generic components, each type has a different purpose and this alone is cause for a wide variety of customization.

5.1.3 ETO – Engineer To Order

The ETO stratagem may provide most advantageous in cases where Denel Dynamics' orders are received with requested customizations for engineering.

ETO is often implemented when no discernable strategy can be identified. By opting for smaller lot sizes, more flexibility can be achieved which does however require the process to provide quick changeovers. *(Sheldon, 2007:35-39)*

Because the product often goes into production even *before final testing has been completed*, the product is engineered and refined within production, which in itself has the potential of causing many delays and disruptions. If the above mentioned changeovers are not handled in a timely fashion, it could prove disastrous for the bottom line.

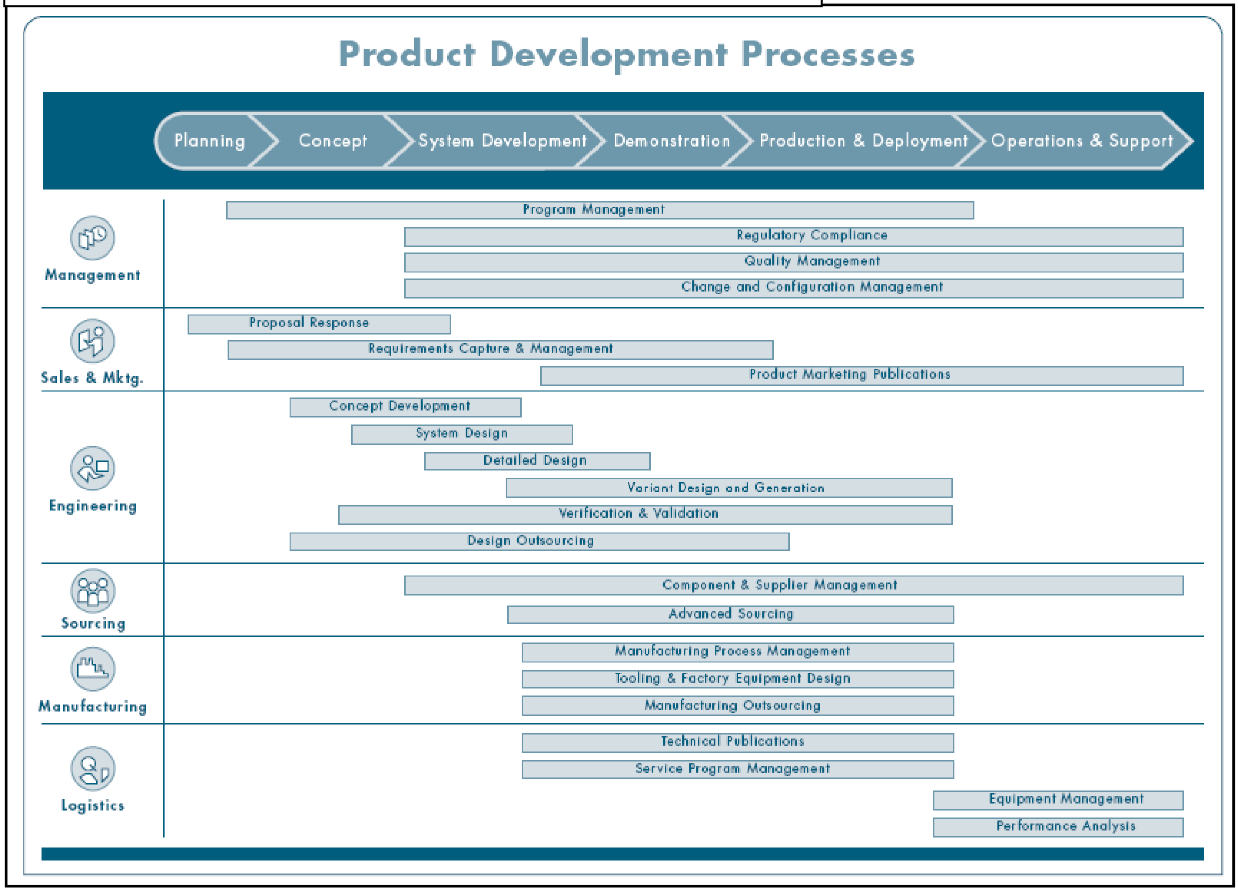
An additional reason for need of the ETO system is the vastly individual needs of their (global) clients. Although a specific product is marketed, the clients' diverse reasons for procuring the product and the various global environments to which the product must adapt, often gives cause for customization.

5.2 Planning

Planning essentially involves converting firm orders and demand forecasts into **material requirements**. The complete planning phase involves many separate processes and consists of high level, medium level and detailed planning. For contextual reasons, the higher planning phases will be described and depicted, although the focus of the project primarily lies in the more detailed level of the MRP (material requirements Planning).

Below is a schematic depicting a typical Product Development Process for the Aerospace and Defense Industry.

Figure 8: Typical Product Development Process schematic for Aerospace and Defense industries. ***PTC (2008:8)***



5.2.1 Production plans (months)

The Production Plan is defined by BNET as "the process of producing a specification or chart of the manufacturing operations to be performed by different functions and workstations over a particular time period. Production scheduling takes account of factors such as the availability of plant and materials, customer delivery requirements, and maintenance schedules". *(BNET)*

5.2.2 Master Production Schedule - MPS (weeks)

Translating a business plan into a comprehensive product manufacturing Schedule that covers what is to be assembled, when, with what materials acquired when, and the capital required. *Business dictionary.* The MPS is also a key component of material requirements planning (MRP).*(Business Dictionary).* Demand forecasts are used as the basis for the MPS.

5.2.3 Material Requirements Planning – MRP (I) (weeks)

MRP I is a computerized ordering and scheduling system for manufacturing industries and uses BOM (Bill of Materials) data, inventory and MPS to establish what material is required, when, and in which quantity. *(Business Dictionary)*

Please see section 6 for a more in-depth description.

5.2.4 Manufacturing Resource Planning – MRP (II)

MRP II, as the name suggests, is the descendant of Material Requirements Planning (MRP I) and incorporates all aspects of a manufacturing firm. Functions such as business planning, production planning and scheduling, capacity requirement planning, job costing, financial management and forecasting, order processing, shop floor control, performance measurement and sales and operations planning is also included in MRPII.*(Business Dictionary).* In essence however, MRP II, simply adds the financial elements to the functions of MRPI.

The above mentioned Planning tools are already an intricate part of Denel Dynamics' planning methodology and will be researched in depth.

6 Problem context and Analysis

In a very broad sense, the problem existing within Denel is that an immense amount of time is spent on the planning stages of a project, yet small discrepancies early in the project more often than not, snowball into a **vast divergence** between the initial planning and the physical execution of the project.

The main cause of these 'discrepancies' is the instability that exists in this particular type of industry and production environment. When faced with instability, one usually has one of two options: eliminate the cause of the instability, or improve planning and management of the instability to react with more agility and to ensure more flexibility in the overhead (main) processes. Removing the said instability will be a daunting task as there can never be just one solution to the problem – especially in a global environment with global suppliers, clients and either a MTO or ETO production environment. Thus more analysis is needed with regards to how this instability is managed:

As described in *section 5*, the main tools currently used by Denel Dynamics to plan and manage their various projects is the business management software, SAP, the most widely implemented software in the world; More accurately, the use of the ERP (Enterprise Resource Planning) and MRP (Materials Requirement Planning) tools provided by SAP.

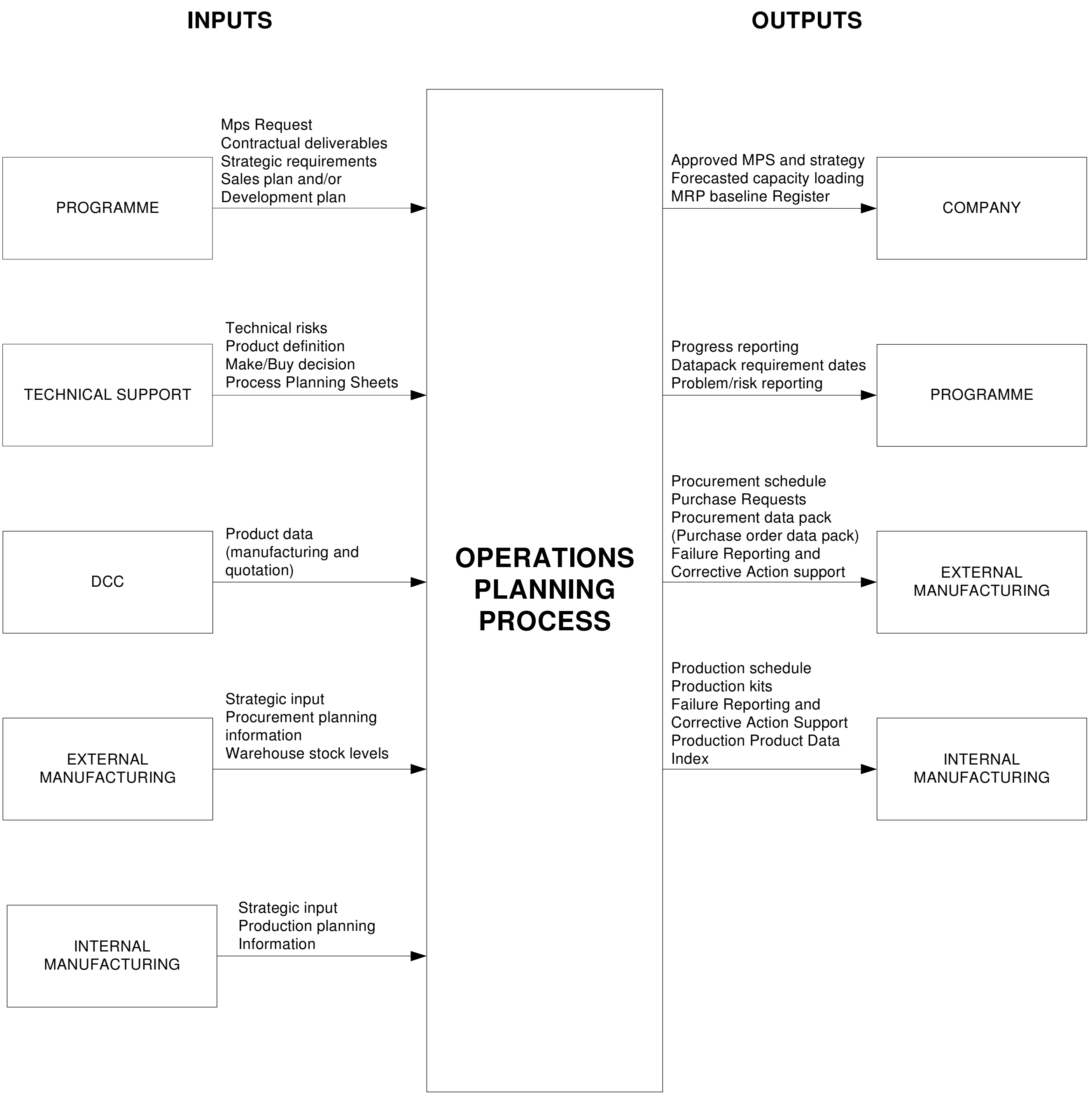
In order to fully understand the problem and before an accurate description can be given, a more in-depth look at the current "As-Is" processes and the conventional MRP system is needed:

6.1 "As-Is" processes

The general and very high level clarification of Denel Dynamics' current planning and scheduling system is outlined in the following diagrams. It is necessary to analyze the current processes in order to identify the weak areas existing in their current planning and scheduling system. In order to remain concise, these processes are shown in schematic form.

6.1.1 Process interaction map: Operations Planning Process

Figure 9: Process Interaction Map: Operations Planning Process



The Purpose of the Operations Planning Process is to ensure that adequate plans are created and executed for the project Master Scheduling. It applies to Planning activities carried out by the Manufacturing Department

6.1.2 Operations Planning Process

Figure 10: Operations Planning Process (Part one)

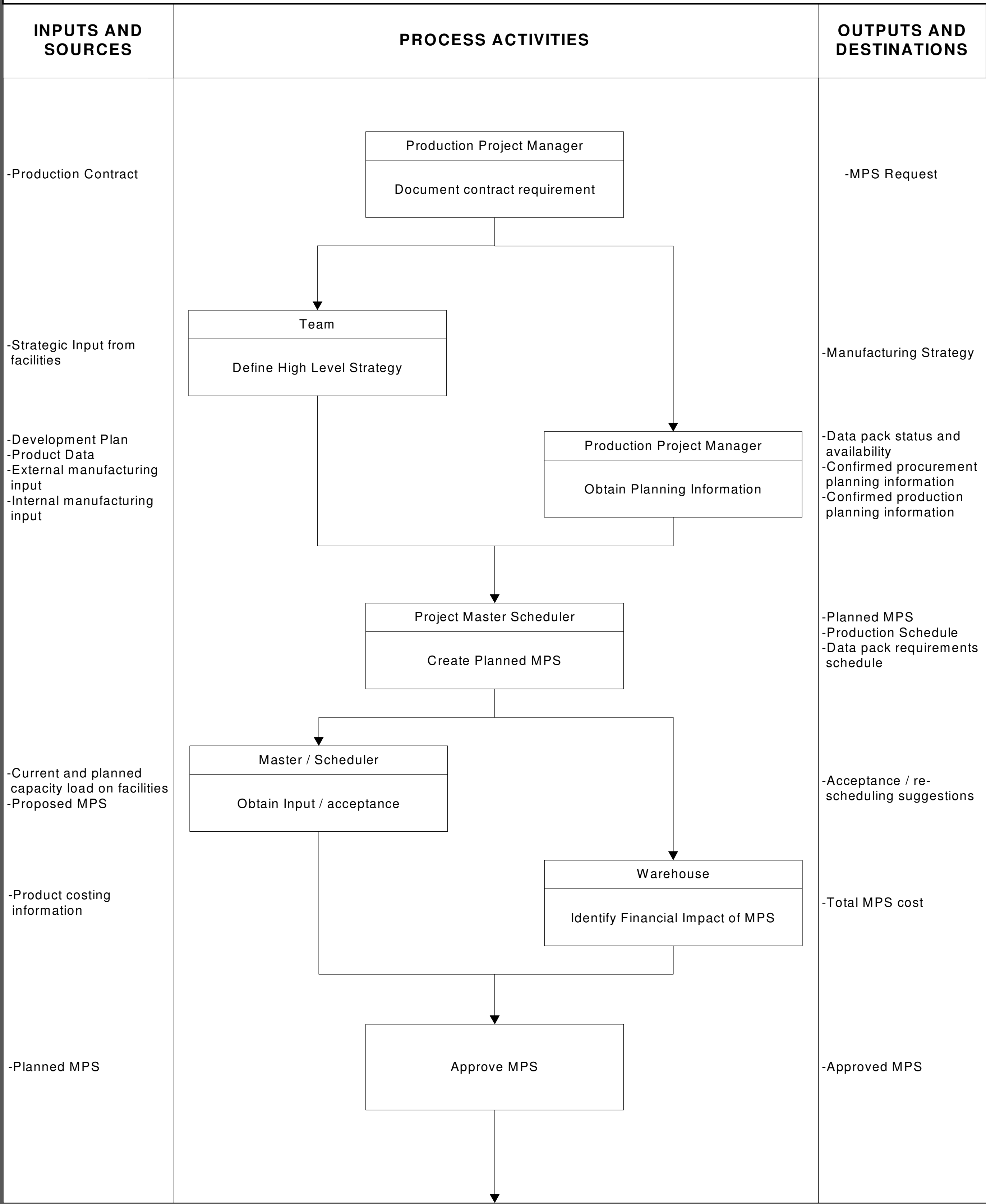


Figure 11: Operations Planning Process (Part two)

INPUTS AND SOURCES	PROCESS ACTIVITIES	OUTPUTS AND DESTINATIONS
-Procurement data pack -Production data pack	**Product Config. Management Board** Confirm data pack	-Confirmed data pack -Updated Product Data Index
-Master Data -Material masters -Bills of Material -Routings	**Planning** Ensure correctness of planning data	-Confirmed planning / Master data
-Approved MPS -Confirmed data pack	**Master Scheduler** Activate MRP in the SAP system	-MRP planned orders -In-house -External -Production schedule in MRP
-Current MPS -Exceptions / Problems	**Master / Scheduler** Maintain MPS	-Updated MPS -Risks identified
-MRP planned orders -Stock levels	**MRP Planner** Initiate execution of MRP detail plans	-SAP Purchase Requisition -Production Orders -Process Planning Sheet
-Order Status feedback	**Planning** Provide progress and problem reporting	-Datapack availability status -Progress reporting -Risk/problem and expediting
-Non-conformance action requests -Problems/queries	**Production Planner** Provide planning support to production	-Solutions to problems -Requested Information -Non-conformance action requests executed
-Non-conformance action requests -Problems/queries	**Material Planner** Provide planning support to procurement	-Solutions to problems -Requested Information -Non-conformance action requests executed

6.1.3 Production Control Process

Figure 12: Production Control Process (Part one)

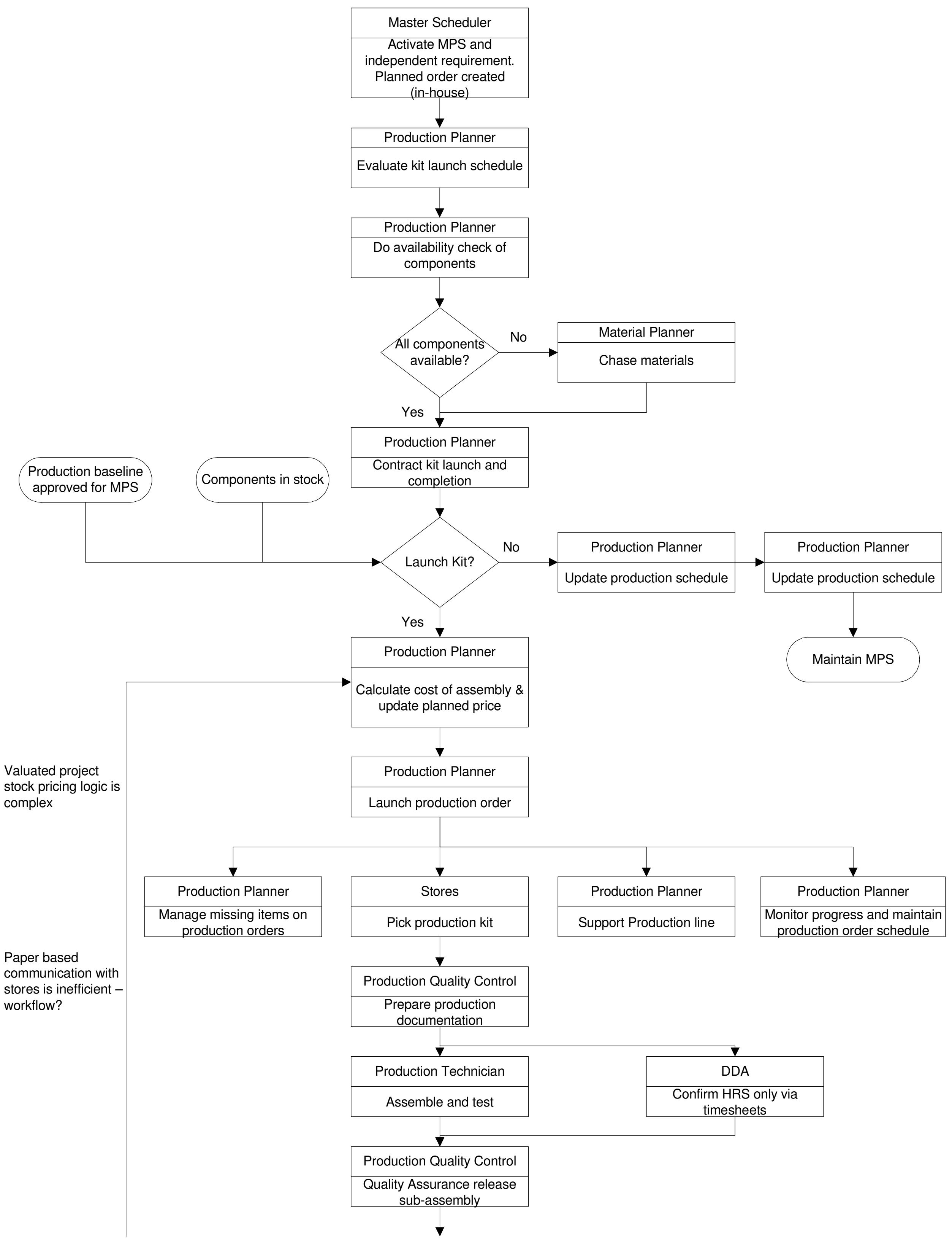
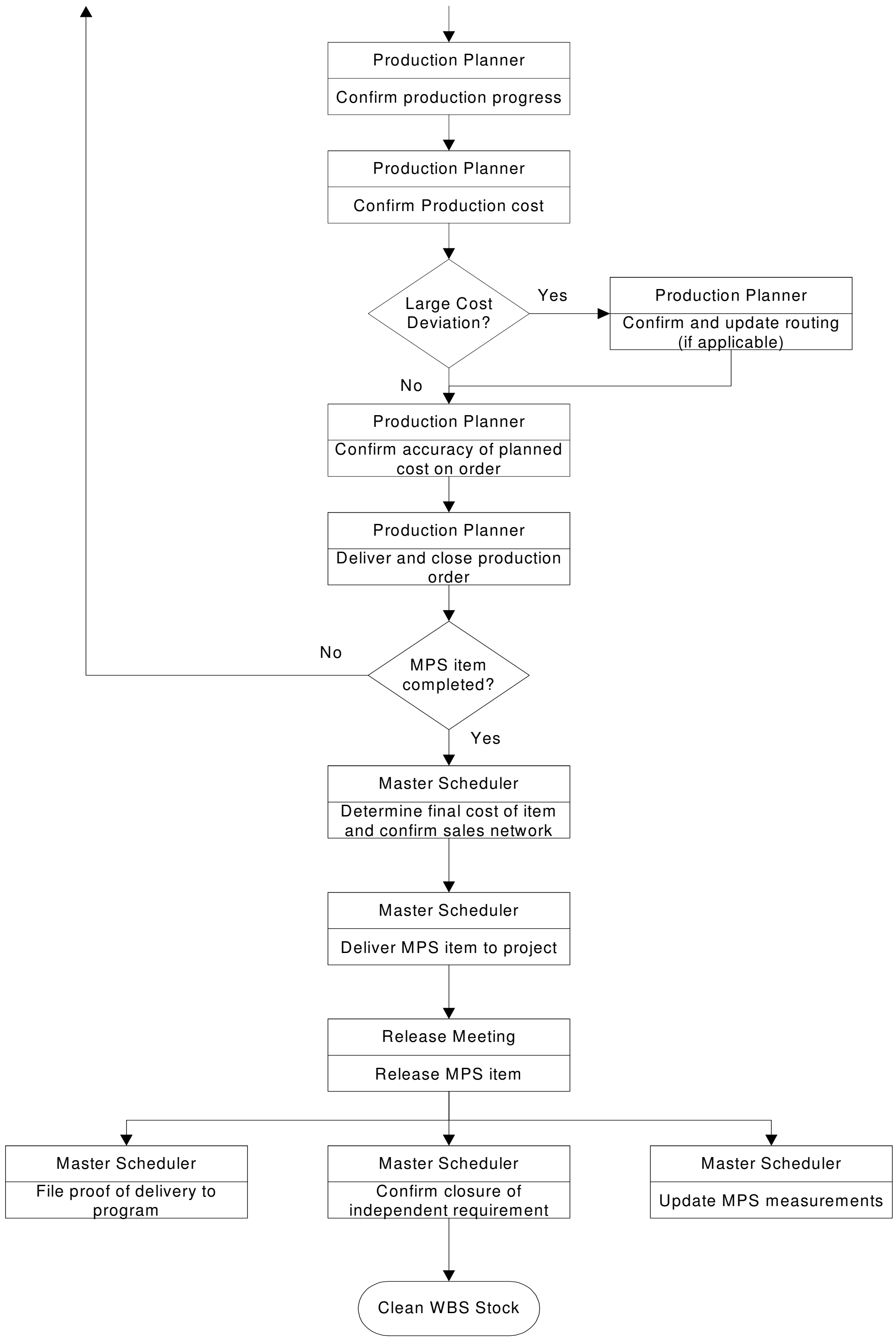
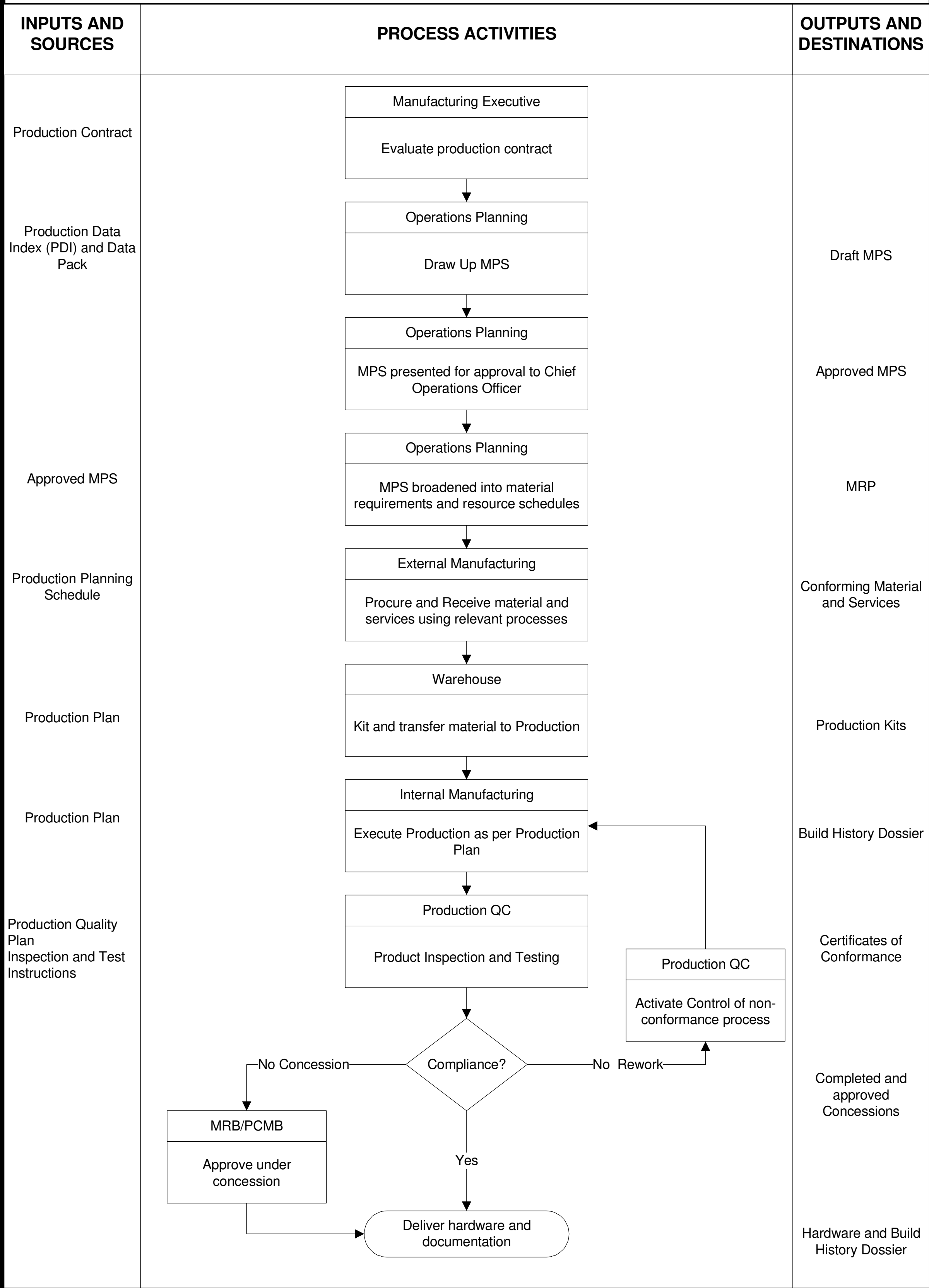


Figure 13: Production Control Process (Part two)



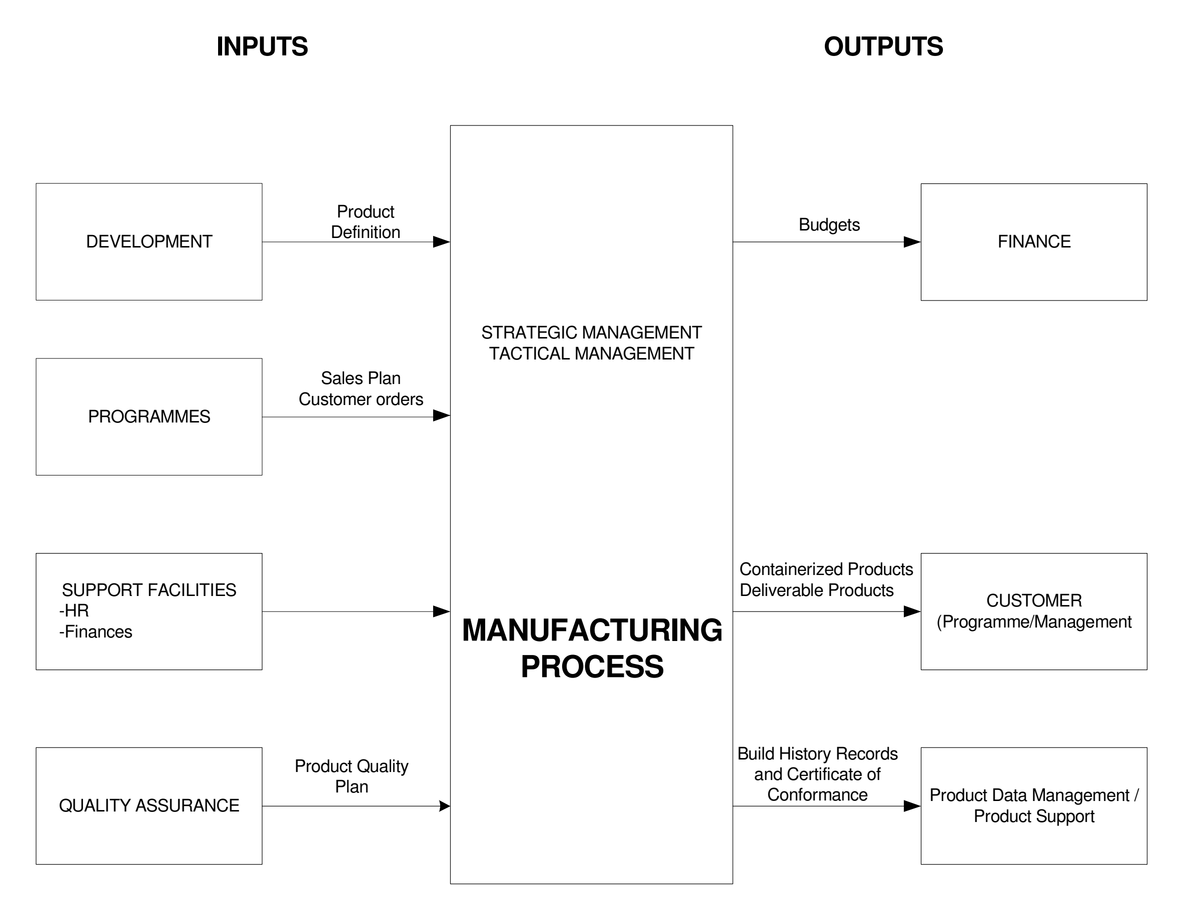
6.1.4 Manufacturing Process

Figure 14: Manufacturing Process



6.1.5 Process Interaction Map: Manufacturing Process

Figure 15: Process Interaction Map: Manufacturing Process

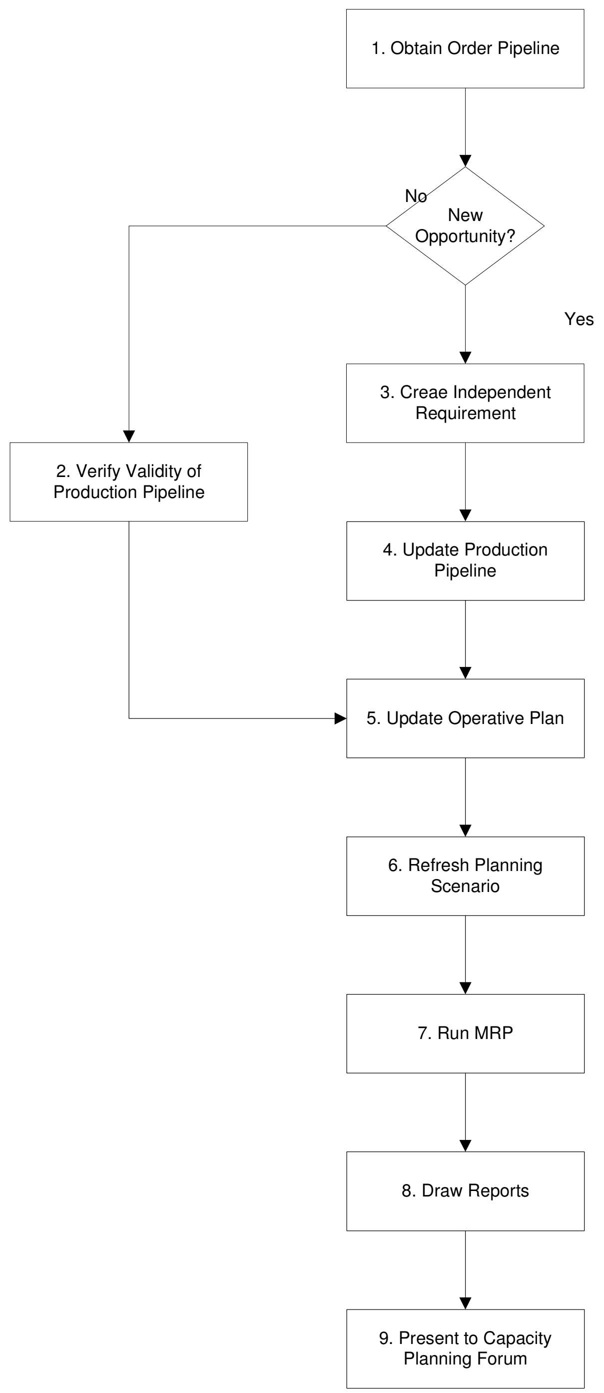


Describes the manufacturing process from when a production contract is received to the delivery of hardware and related documents to the program.

It applies to planning and production activities carried out by the Manufacturing Department. The controls specified in this process are applied to subsystems and complete systems manufactured and / or integrated by Denel Dynamics.

6.1.6 Capacity Planning Process

Figure 16: Capacity Planning Process



The focus of the process is the Supply Chain Environment. Its purpose is to formulate a rough-cut plan based on sales order pipeline.

-To achieve focus alignment and synchronization among all the functions of the organization and provide realistic inputs to Projects.

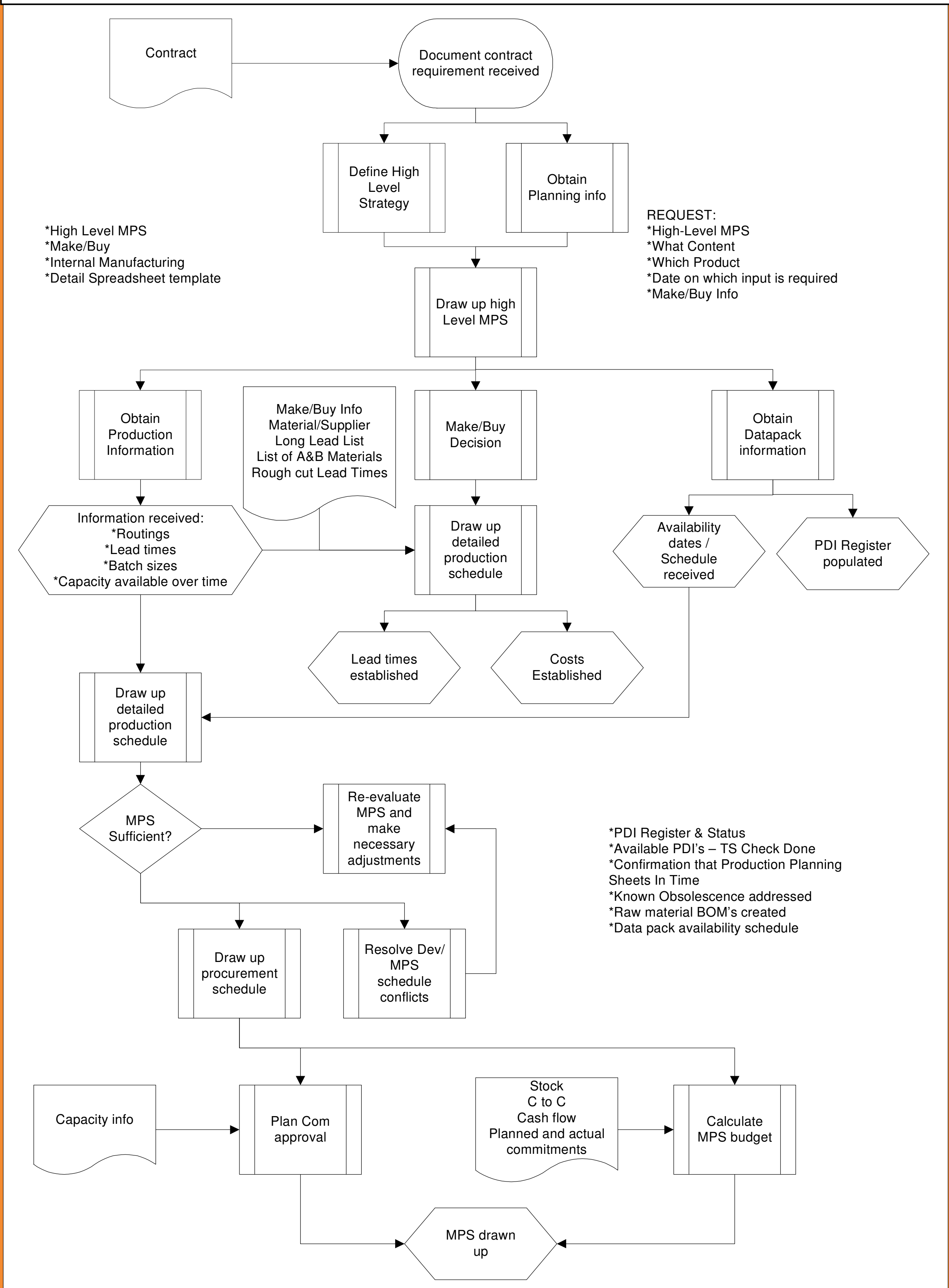
-To enable effective Supply Chain Management and High level Resource Requirements Planning.

-The ultimate goal is to always keep the detailed sales, manufacturing, purchasing and capacity planning systems in synchronization with the latest high level plans of management.

-All departments should be brought to executional alignment.

6.1.7 MPS: Master Production Schedule

Figure 17: MPS Process



6.1.8 Materials Planning

Figure 18: Materials Planning (Part One)

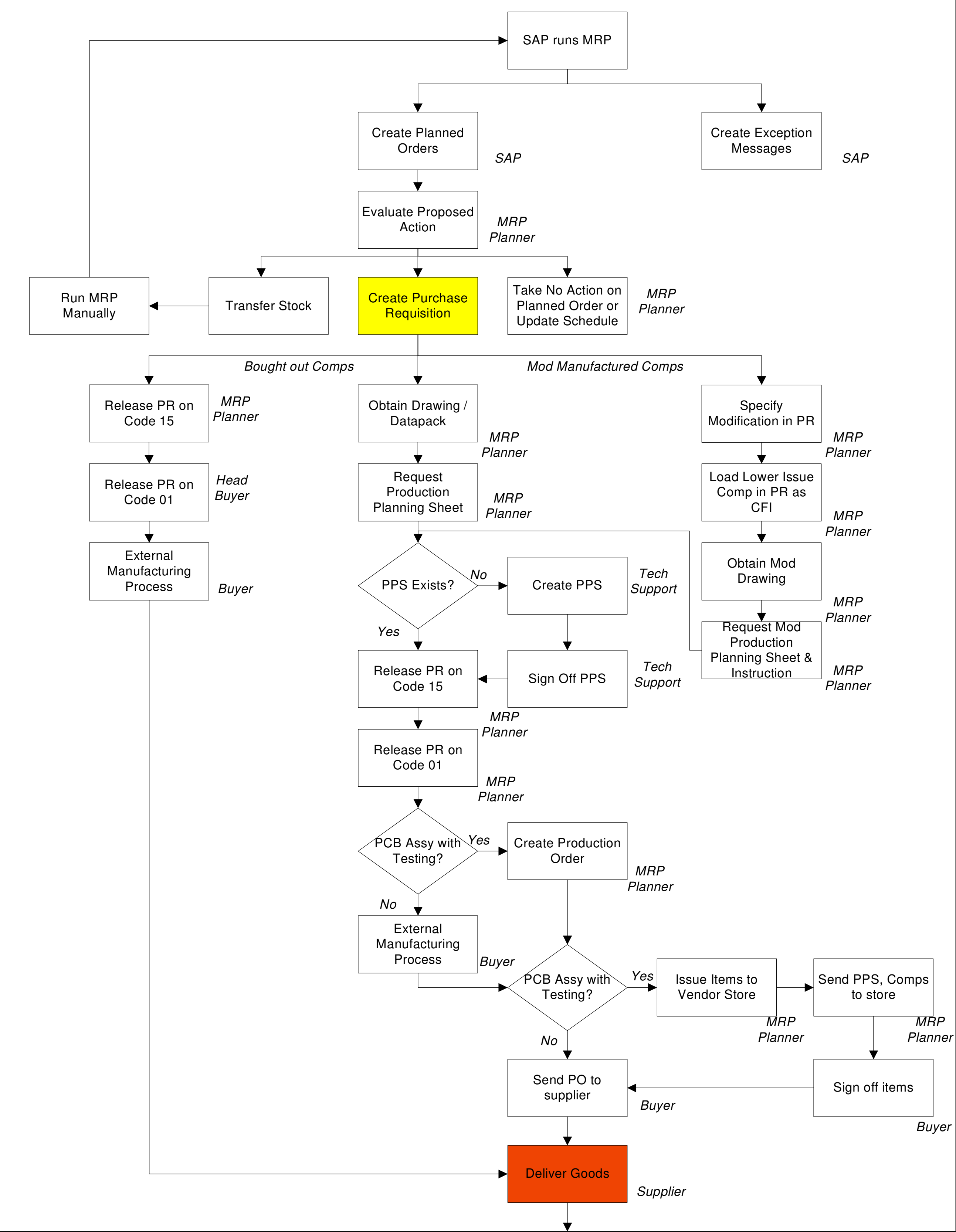
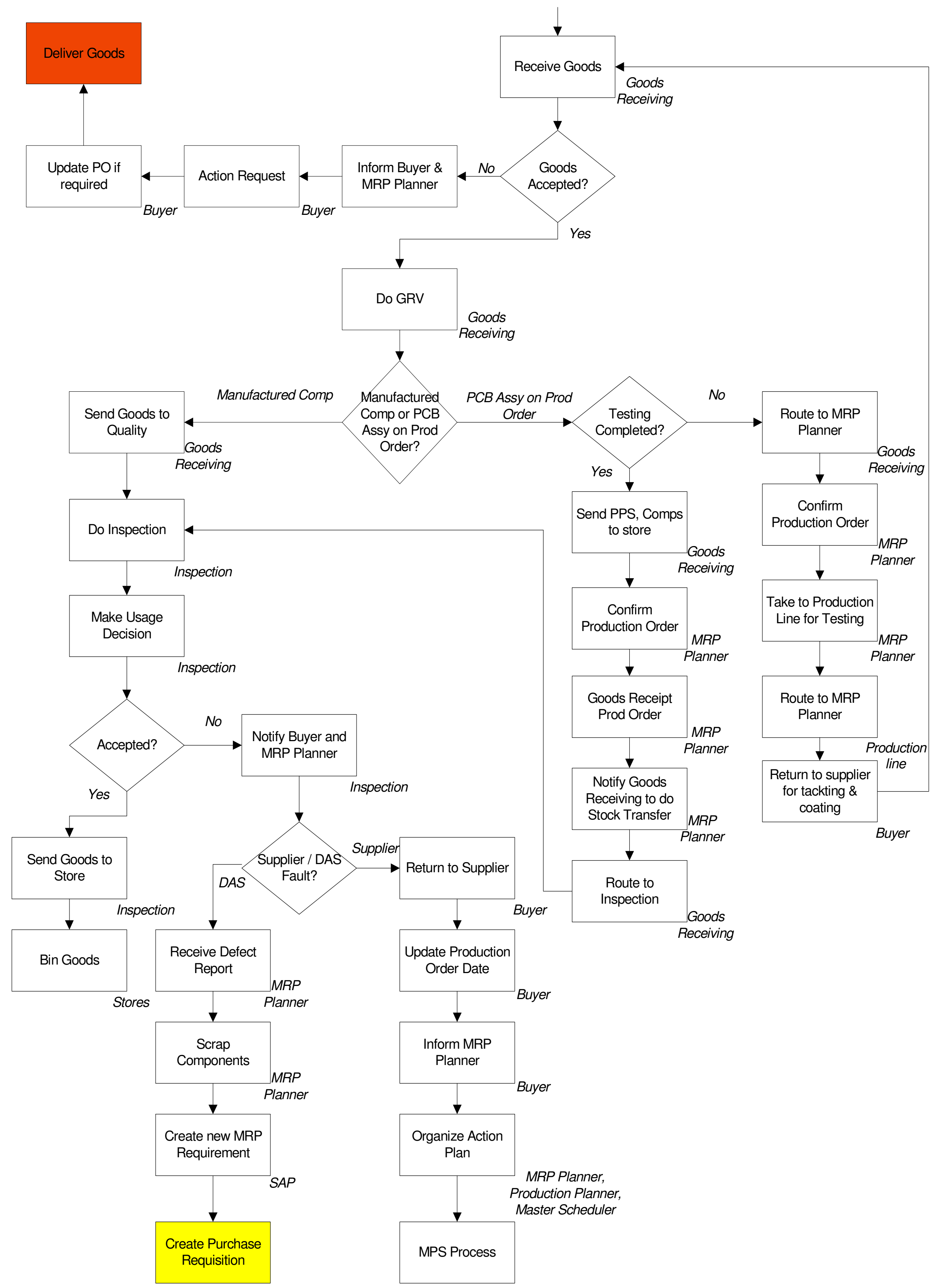


Figure 19: Materials Planning (Part Two)



6.2 MRP: Material Requirements Planning

Every product manufactured within Denel Dynamics starts off with a *Material Requirements plan* (MRP); this is the basis of planning on which Denel Dynamics schedule all tasks, processes and ultimate production of the required end product.*(See figure 18 & 19)*

As the name implies, MRP is used for requirements planning by making use of a simple algorithm. This algorithm has been used for decades, and was first implemented by *Joe Orlicke* at *J.I Case* in Racine, Wisconsin. Since its computerization in the 1960s, it has grown considerably in function, implementation and popularity.*(Waddle, 2009)*

The MRP schedule is in essence a plan to help determine the sequential order in which certain production activities need to take place. In the environment of Denel Dynamics, the SAP MRP (Material requirements Planning) system is used for this purpose. The system starts with the end/delivery date (when the item will be needed) and works backwards from that date determining when each action should be completed by before another one can be started in order to finish in the available time. In doing this, the system calculates a start date for each item. If the start date does not lie in the future, it means that the planned actions do not fit into the time frame and *the project will overrun*. The system will then change the approach and do forward scheduling from the present date and calculate an end date that will be viable.

By following this procedure, the various process elements will always start Just-In-Time (JIT). The JIT strategy is programmed into SAP and will ensure that an item is not finished too early or too late but exactly when it is needed. This strategy is more aimed at the *mass production environment* (i.e. high volume), and creates problems in a project orientated work environment such as Denel Dynamics because it does not leave any space for error.

The MRP is based on a *Master Schedule (figure 17)* which in turn is developed from the *Production Plan* with demand forecast usually an important input. The specific parts and materials required to produce components are extracted from the BOM (Bill of Material) as well as the *routings*, which define the labor time, work center location and sequence in which the item is created. *(Please see Addendum A for a typical BOM at Denel Dynamics)*

The conventional system of MRP at first glance seems to be a convenient solution to most production scheduling problems. In most cases however, *as will be shown in this project*, the conventional MRP proves insufficient and time consuming without providing significant benefits to the bottom line.

Doug Bartholomew, 2006, commented on the inexplicable and continued survival of the MRP system even though its shortcomings are becoming more apparent. In 2004 and 2005, 80% of companies were using the MRP system and a further 8% were planning to implement it. *(Bartholomew, 2006)*

MRP was however initially designed to handle **high volume productions** based on a *push system.* Companies have however come to realize the potential in *Pull systems* (as are used by Denel – *section 5.1*) originating in Japan, and are consequently trying to implement a push system methodology to a conflicting leaner approach based on the Theory of Constraints (TOC).*(Aquilano, Chase, Jacobs, 2006:628-647)*

Because of these conflicting principles, managers and planners are forced to "ignore" and circumvent some of MRP's more detailed planning processes and are attempting time-consuming and inefficient **compromises** to the existing MRP system.

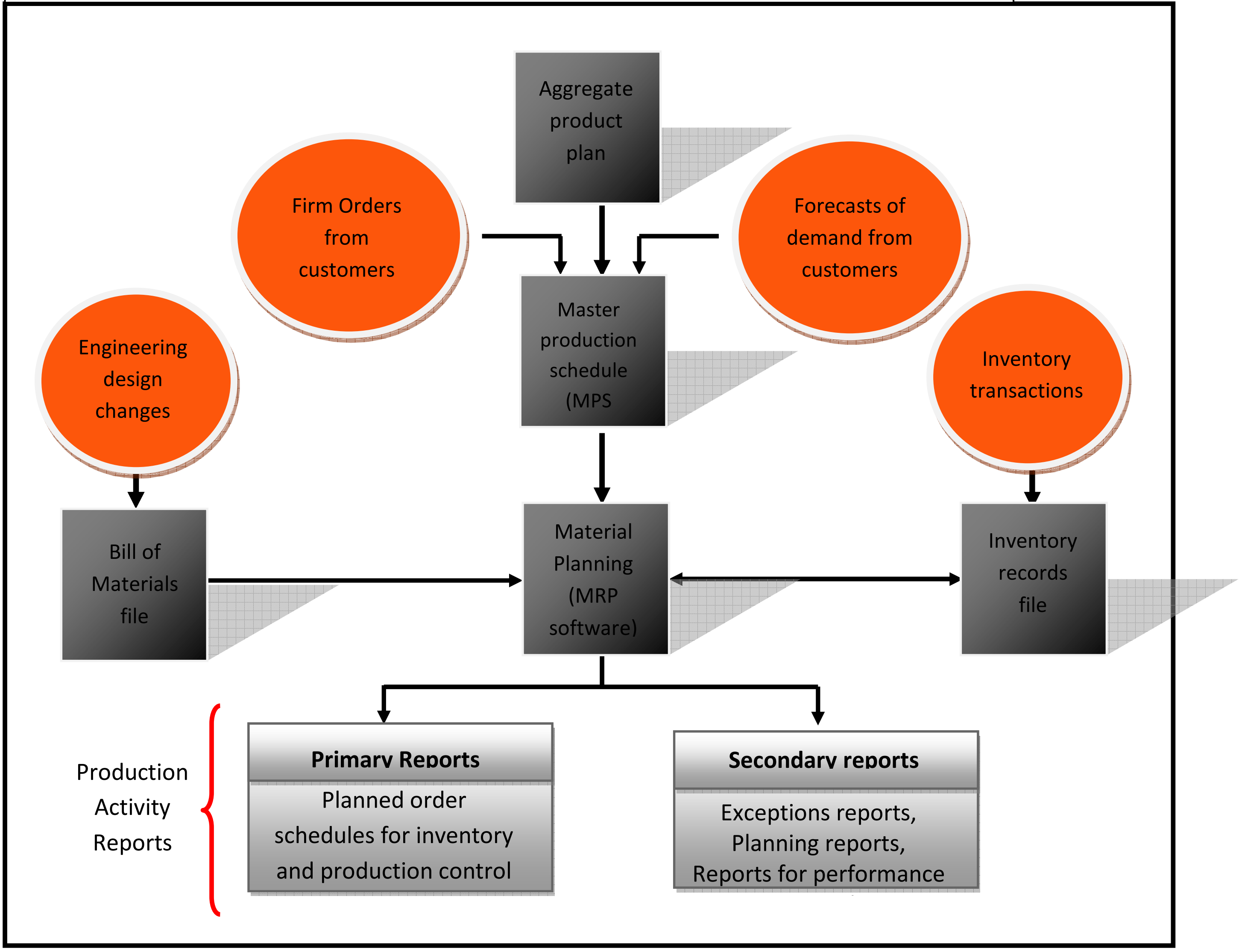
In a study carried out by the *Technische Universiteit Eindhoven* in the Netherlands, it was concluded that planners often disregard the suggestions and warnings given by the planning software. Planners are given an option to update the schedule manually or (in some cases of software applications); the software can be given appropriate parameters to continue with this update manually.

Research done by *Fransoo J.C and Fischer, D* found that experienced planners were increasingly neglecting the software suggestions given by the Planning systems. When questioned, these planners commented that the software did not (in their opinion) give the correct estimates as the software was not entirely applicable to their production environment. *(Fransoo & Fischer, 2005)*

6.2.1 Basic MRP Methodology

The diagram below depicts the various inputs to a typical Material Requirements Planning (MRP) Program as well as the reports it generates as outputs.

Figure 20: MRP: Inputs and Reports, *Aquilano, Chase, Jacobs (2006:636)*



6.2.2 Critique on MRP and subsequent Compromises

Although MRP and similar methodologies have been used over decades in an attempt to efficiently plan and synchronize production, supply chains in general are still struggling to refine the process of planning effectively. Two main reasons can be identified as the main causes of this dilemma:

6.2.2.1 MRP facing modern-day challenges:

Variability and volatility is a reality of the nature of modern manufacturing environments – especially when considering the aerospace and defense industry. This has necessitated the implementation of Lean and TOC methodologies which places tremendous pressure on conventional MRP systems.

A symptom of globalization is that capacity far exceeds demand, giving the customer more freedom of choice and increasing organizations' need to remain competitive. This need for competitiveness forces companies to consider its entire supply chain context as well as its internal circumstances with influential factors such as: new materials, inaccurate forecasts, increasing product customization and subsequent complexity, demand for lean inventory, global suppliers, material shortages and long lead times

The reality is that MRP was designed in the 1950s, software systems were implemented in the 1970s and it has since barely evolved. MRP was never designed to deal with modern *Pull – systems.*

6.2.2.2 Forced Compromises

Most companies are aware of the inherent limitations of MRP systems - which have grown increasingly apparent over recent years. Certain characteristics of MRP are still necessary, but are over shadowed by its complications and the subsequent, forced compromises which incorporate the needed characteristics while simultaneously bypassing the problematic aspects.

- **Manual re-work:** In order to bridge the gaps present between conventional MRP systems and the modern production environment, tools such as Excel and/or Access are used to customize the data MRP cannot. Companies revert back to more "primitive" measures of calculating and managing production and the scheduling thereof, effectively voiding all efforts made by the "sophisticated" ERP systems designed exactly to avoid such measures. Attempting to integrate these manual tools only increases the complexity as they are in themselves very restricted.

- **Simplify the Bill of Materials (BOM):** This refers to "flattening" the BOM in an attempt at better synchronization. This translates to removing certain levels of dependencies both within and across product structures - which only helps when adequate experience is applied in selecting the appropriate product structures to flatten and *avoiding the elimination of core structures*. Visibility can actually be lost when removing some of these dependencies, and contrary to popular belief, many companies will in fact benefit more by enforcing the dependencies correctly and through the *addition* of a level to the BOM.

- **Make to Order:** This strategy (compromise) is already prevalent within Denel Dynamics and is being implemented by numerous companies. The result is more raw material, work in progress (WIP) and a greater need for capacity and resources in order to avoid lead times exceeding that of the promised project due date. MTO significantly increases the challenges involved with providing the customer with a quality product within the prescribed time.

- **Improved Forecasting:** In terms of Denel's methods / practices / methodology / processes, forecasting is used for the demand input at the high level MPS (Master Planning Schedule) which in turn, is needed for the MRP (Material Requirements Planning) schedule.

  Forecasting is the estimation of the value of a variable (or set of variables) at some future point in time. The *Business Dictionary* defines forecasting as follows: "Forecasting is a planning tool which assists management in its attempts to cope with the uncertainty of the future, starting with certain assumptions based on management's experience and past data." These estimates are projected into the coming months or years using techniques such as Box –Jenkins models, Delphi method, exponential smoothing, moving averages, regression analysis and trend projection.

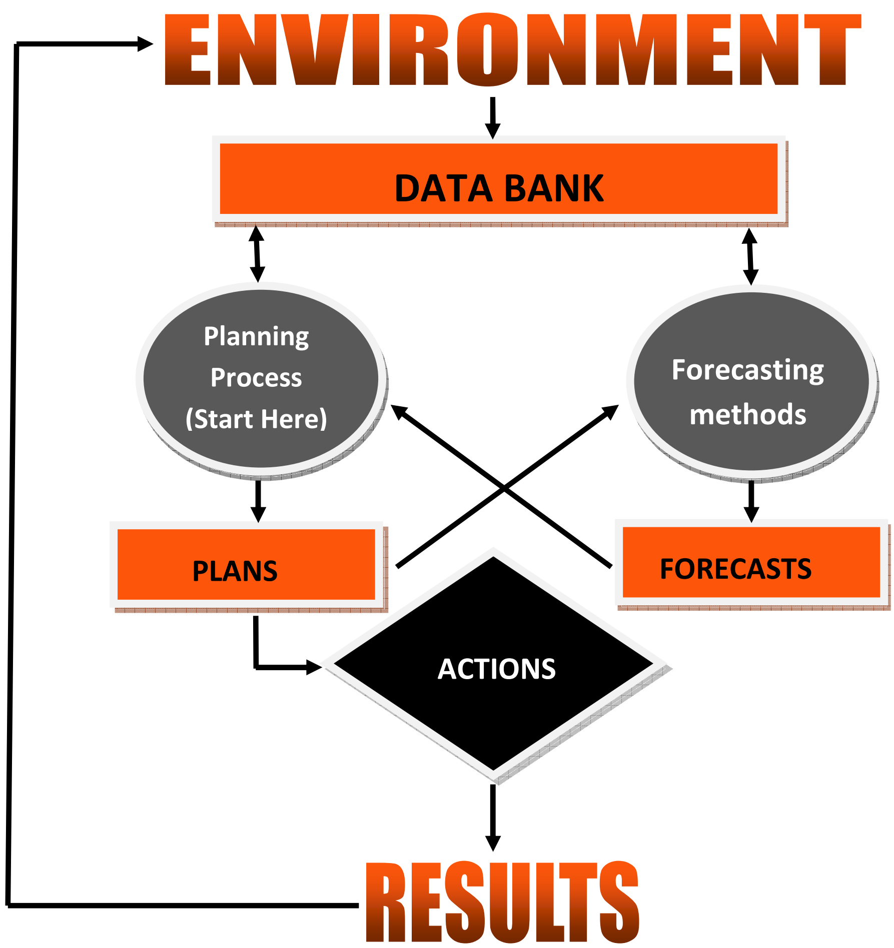
Sensitivity analysis is used in conjunction with forecasting to account for possible errors in the initial assumptions and their subsequent impact.

Planning and forecasting are used in conjunction. It is however important to note certain distinctions:

- Planning provides the strategies, given certain forecasts, whereas forecasting estimates the results, given the plan.
- Planning relates to what the firm should do while forecasting relates to what will happen if the firm implements a given strategy in a possible environment
- Planning provides possible scenarios whereas forecasting helps to determine the likelihood of possible circumstances.

A logical conclusion to draw is that by improving the forecasted demand, the benefit could potentially also result in improvements in the more detailed planning. However, even if forecasting accuracy is improved, the potential advantages do not filter through to benefits to the bottom line or even effectiveness in fill rates. Improved signal accuracy is easily undone by supply side variability and volatility.

Figure 21: Forecasting and Planning



6.3 Problem Definition and Characteristics

The problems Denel Dynamics face that prohibits them from suitably aligning the planinng and execution phase transpires from inadequate scheduling. As the MRP methodology is core to production planning, the core problems of MRP are also converted into the whole production system, causing a significant divergence and severe discrepancies between the original, planned costing and duration of the project(s) and the actual end result..

Long production runs prevalent in Denel Dynamics' environment, is a by-product of the low volume, high complexity production process. Extensive customization of components is standard practice, which in turn also results in **high vertical integration**.

Even if an order of a standard, existing product (not a newly designed one) is placed, much of the data, suppliers and resources must be acquired or procured from scratch, worked out as new and /or updated for the current environment as the details of the product's previous production run is no longer viable or valid.

Every order is thus handled "as new" with new set up procedures, scheduling, costs etc. In this context, the problems to be addressed by the project are as follows:

- **Key Performance Indicator of on time delivery is rarely – if ever met**
- Repetitive, time consuming and labor intensive re-scheduling is frequently needed during the course of the projects
  - Re-scheduling cannot currently be done automatically by the MRP software and because rescheduling is too time consuming and labor intensive, the current procedure is simply to *let the project run its (non-defined) course,* without having any indication as to the new completion date of the project.
- Inadequate Resource scheduling and balancing
- Early task finishes not utilized
- Exessive task duration estimates with time wastage and Parkinson's Law is widespread and rife.*(see section 8.2 on Parkinson's Law)*
- Multi-tasking increasing project lead times significantly
- Increased costs due to time delays
- Loss of competitiveness as a result of stagnating processes and project delays.

Part C: Solution: Scheduling to Align Planning and Execution

7 Refine and improve Scheduling Techniques

Companies are realizing the shortcomings of conventional MRP every day, and this has already lead to some significant advances within the discipline of Production Scheduling.

... MRP 3.0 is also on the horizon...

MRP II (Manufacturing Resource Planning) is implemented by various organizations who can take advantage of the expanded purchasing and financial elements. However, MRP II does not provide a solution to Denel Dynamics' problem.

MRP 3.0 is also on the horizon. *Mr. Chad Smith*, a co-author of the intended text confirmed that it will be available during the first quarter of 2011 and will be published by McGraw-Hill.

Not much is known about this next generation MRP as of yet, but many companies are waiting in great anticipation for the much needed new perspective on an almost archaic scheduling system.*(Smith, correspondence)*

The latest advances in the scheduling environment all point to progress and innovation.

From *section 6.2* and *section 6.3* it is clear that most of the problems apparent in Denel Dynamics' environment stem from inadequate scheduling, conflicting theory applications (push systems versus pull) and the inherent complications arising from attempting to implement scheduling and planning systems which are no longer as suitable to the production environment as it once were.

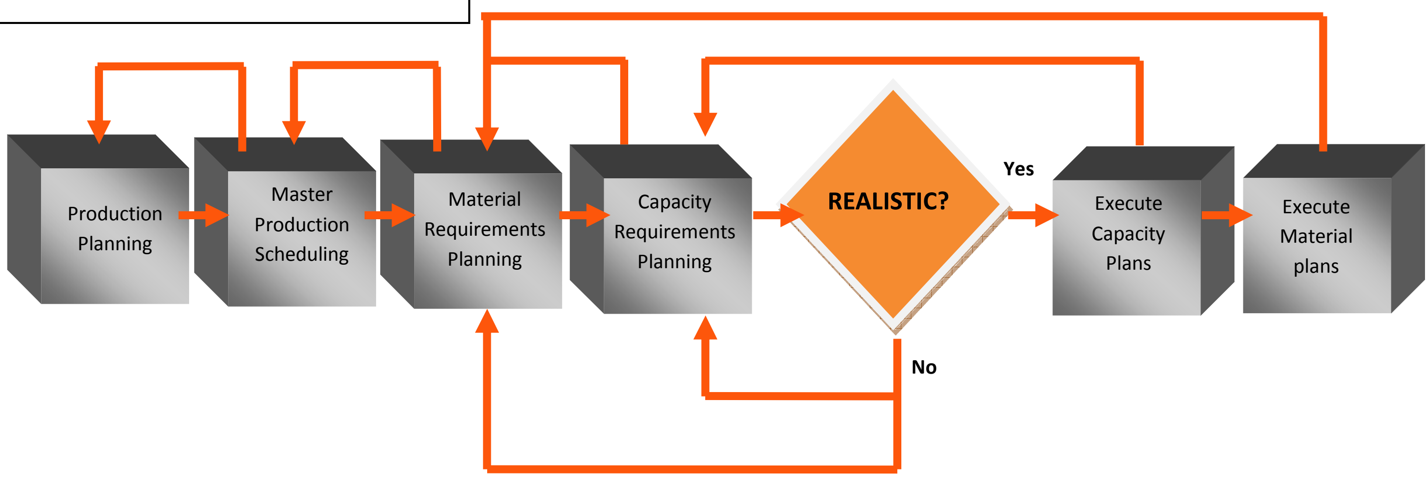
From this the proposed solution to align the planning and execution phases at Denel Dynamics lie with implementing a more innovative scheduling methodology in an attempt to reduce project lead times and increase the reliability and frequency with which Denel Dynamics accomplishes the originally scheduled due dates of their various projects.

7.1 Closed Loop MRP

The first suggestion to address the frequent need for re-scheduling and attempt better control and management over production activities, would be to examine the current MRP algorithm and logic and adjust it in such a way that rescheduling could be done in a more efficient and effective manner.

Closed-loop MRP is defined as an MRP system which has information feedback from its module outputs; a system that includes the additional planning functions (such as financial) and incorporates reports of delays and progress to continuously compute new task time estimates and the ultimate project completion date. *Aquilano, Chase, Jacobs (2006:647)*

Figure 22: Closed Loop MRP System



Closed Loop MRP however, only addresses the first part of a greater problem and even if it should prove adequate at the far-reaching implications of re-scheduling the project, the only outputs will potentially be the new project completion date – even if it is still outside of its originally planned boundaries.

Closed loop MRP cannot keep the project aligned with its execution and will simply state by exactly how much time you have failed.

7.2 ASR – Actively Synchronized Replenishment

As described in the *ASR Whitepaper* published by *The Constraints Management Group* in 2008, ASR is a methodology that looks “beyond MRP” for solutions to the specific challenges companies face today.

The Problems that ASR claims to address include the following:

- Recurrent Material Shortages
- Pull system conflicts with Push systems

ASR also addresses some of the MRP constraints, workarounds and compromises and benefits include:

- Reduction in variability by protecting and increasing material and Work In Progress flow
- Improved lead times to ensure continuous competitive advantage
- Improved quality and performance
- Improved inventory Management
- Continuous management and alignment to improve execution

ASR is a very promising methodology and addresses many of the issues companies are facing in terms of the conventional MRP. The methodology is however somewhat intricate to implement and a total system “overhaul” will have to be executed to ensure success of its implementation. *Constraints Management Group, 2008*

8 Critical Chain Scheduling as Solution

8.1 Critical Chain Scheduling and Buffer Management

There is some measure of uncertainty and instability in every project, every design and every production plan. *Frank Patrick (1999)* defined this uncertainty by referring to two well known “laws”:

- **Parkinson’s law: “Work expands to fill (and often exceed) the time allowed”,** and
- **Murphy’s law: “Whatever can go wrong, will”**

Although one can rarely (if ever) completely mitigate these uncertainties or “laws”, they can be alleviated and managed.

These laws have caused many time disruptions and costly delays and/or rework to various companies – including very noticeably, Denel Dynamics. Regardless of the type and nature of a problem that arise, *the bottom line is simply that it will cause a time delay* in the project end date and that costs will most likely expand.

Even after re-scheduling and even sometimes managing to keep the project aligned with the original plan and schedule, these persistent “laws” still manage to creep in and cause disarray.

To eliminate these uncertainties, risks and instabilities is a daunting task - if at all possible - and thus the only course of action remaining is to be aware of these inevitabilities and to prepare sufficiently to manage any problem (time delay) that might arise. Better management of these potentially harmful circumstances in the first place, could help one to avoid rescheduling all together, or at least break it into more manageable sections, thereby increasing the frequency with which one reaches the originally planned (and self-imposed) deadlines. (*Ptak, C. & Smith, C.2008)*

Critical Chain Scheduling has a holistic view of projects which allows for circumventing the main impact(s) caused by Parkinson’s Law at the detail level, while managing the instances of Murphy’s Law at a higher level.

It is also important to note that at the core of CCS lies in the elimination of a concept we have all become so accustomed to: **Task deadlines.** By eliminating individual task deadlines, the negative effects of both Parkinson's and Murphy's Law can be managed, and perhaps avoided in its entirety. This certainly seems radically unconventional – but only because we have grown to live with often impossible deadlines and are somewhat comfortable with handling our tasks as such even though it puts immense pressure on all resources.

There are however challenges that arise from the elimination of individual task deadlines, which include:

- Protecting the final completion date as well as the influences of Parkinson and Murphy without having the progressing task completion dates set in stone,
- taking advantage of activities finishing ahead of schedule and using the buffer replenishment to allow the project to finish early,
- enabling better resource management in a multi-project environment, and
- managing the project's progress during execution without having target progress dates to track.

Before explaining how CCS addresses the listed challenges, it is important to first take into account how the uncertainty factors influence the course of a conventional project.

8.2 Parkinson's law and how it happens

The "law" was already recognized and subsequently published in November, 1955 by C. Northcote Parkinson in an issue of *The Economist.* Put in simpler terms, Parkinson's Law refers to "due-date behaviors" that give the illusion that if a project is completed within its (buffered) deadline, it is assumed to be on course or on target.

This type of thinking causes one to use all the time available and thereby losing the advantage of early finishes that might have alleviated delays in other areas of the process. These decisions are however usually subconscious and result from priorities being unclear.

We waste the "safety" of additional time buffers exactly because of the comfort it provides

8.2.1 Causes of Parkinson's Law

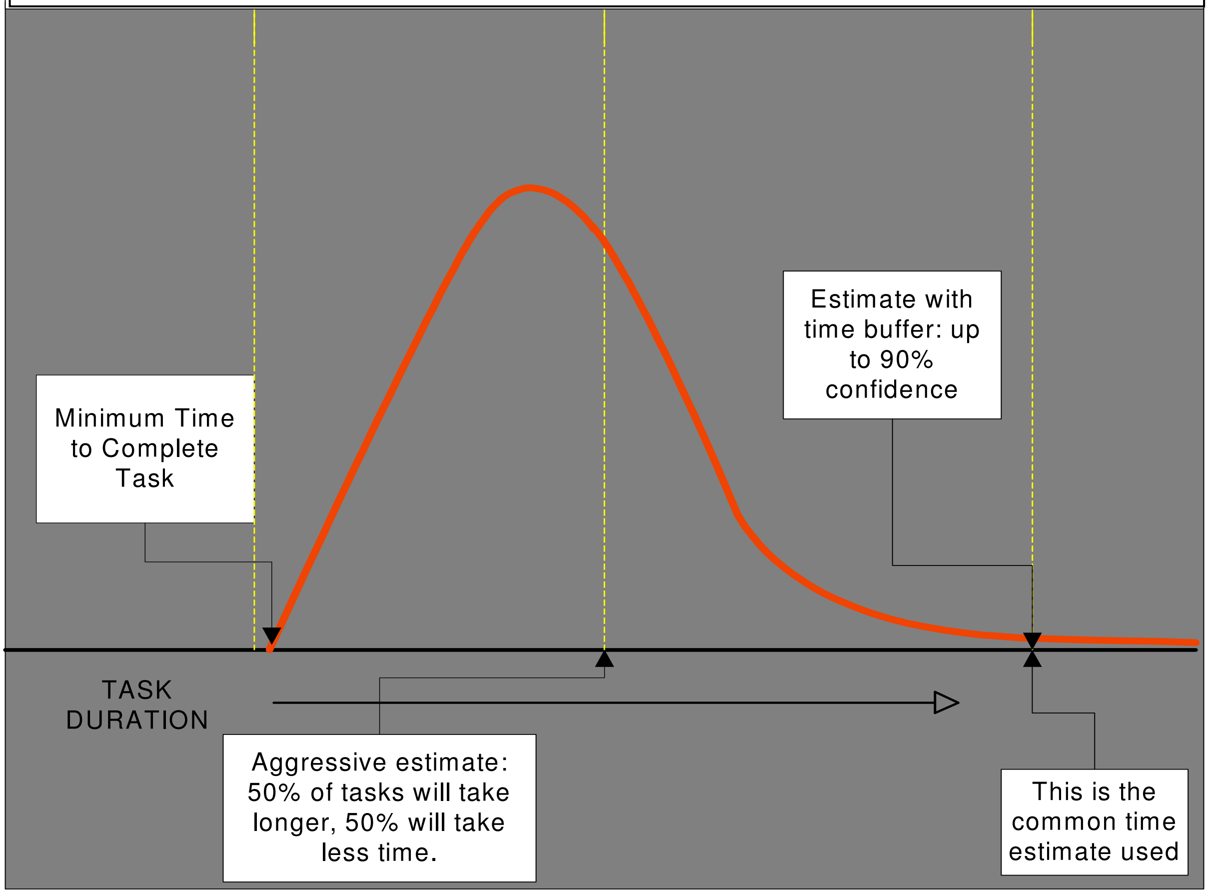
There is increasing pressure on projects do deliver at a higher rate and quality as well as with more consistency. Planners must deliver highly competitive project outcomes with certainty, while dealing with uncertainty during the project itself.

The way this uncertainty is managed is of the utmost importance to all performance measures and the conventional way of attempting this is by assuming that if all individual tasks are done within their time-frame, the project will reach its specified deadline – this is however not the case.

Ultimately, the only date that matters is the due date of the project. CCS focuses on the project as a whole with the individual tasks taking on a lower priority together with the elimination of individual task due-dates in order to avoid the eventuality of Parkinson's Law.

Production Schedules are developed form *estimated* durations for each separate activity, and it is this estimation (Not a single number but rather a *probability*) that is the root cause of the lost time.*(Patrick, F. 1999)*

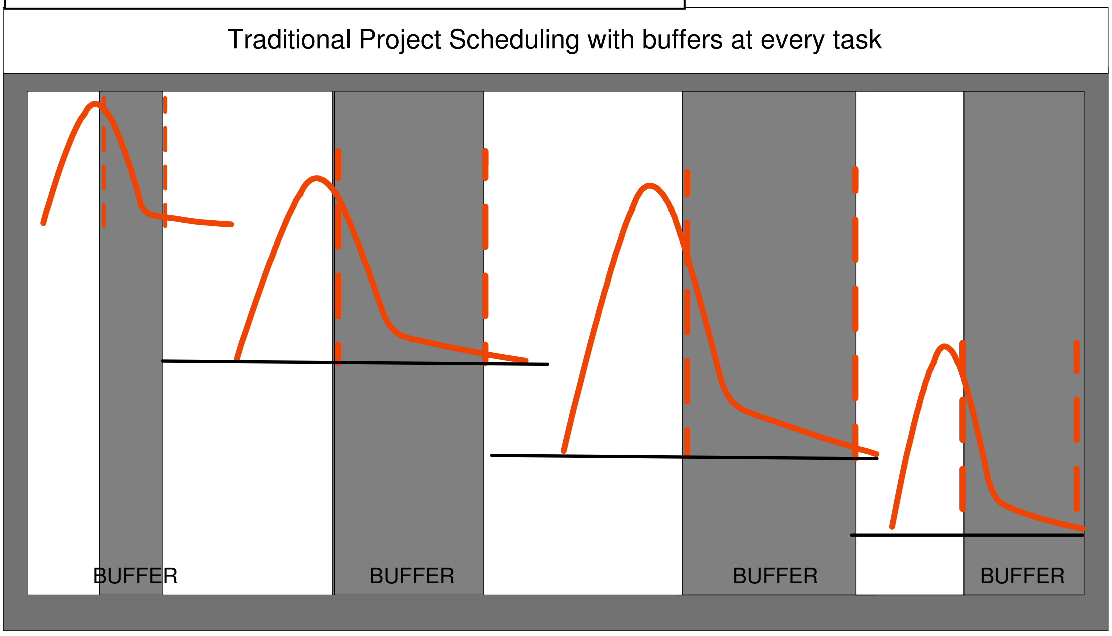
Figure 23: Conventional task duration estimation



For the planner to provide an estimate of duration, he can only do so with 50% confidence, but if a "buffer" or safety is included in that time estimate, the confidence level rises to between 85% and 95%. The buffer is frequently *the greater portion* of the estimated time, thereby increasing the scheduled time two – to three fold.

This large amount of "buffered time" seems excessive, yet most often than not, projects (especially in this particular environment) use the buffered time very rapidly, and the critical project deadline is pushed forward, sometimes indefinitely.

Figure 24: Traditional Scheduling: Buffered tasks



The reasons for this include:

- Simply having an enormous amount of problems and errors inherent in the system,
- the applicable project is pushed-back because staff is still completing the previous project or because of wide-spread multi-tasking, and
- the most common: that a project is started extensively past its due 'start date" as there is a seemingly abundance of time - exactly because of the incorporated buffer

Another problem with conventional buffer-scheduling and the above-mentioned line of thinking is that even when an activity *does* finish ahead of time, the resource required for the next task is unavailable or pressured with urgency to take up the task.(Note how the before-mentioned issues relate to those described in section 6.3). In all probability, the project will at best only achieve its due date with overworked staff, and compromised quality. More likely, unfortunately, is that the project will still miss its originally planned deadline / due date; Parkinson's Law has struck.

8.3 How CCS addresses the issues

8.3.1 Changing the focus back to project completion.

The only date that matters, is the final completion date of the project. Protecting and achieving this date while taking Parkinson's squandered safety time into account, takes careful planning and innovative thinking.

The need for buffered time usually originates from one (or all) of the following:

- Multi-tasking – working on various projects simultaneously
- Instability and uncertainty caused by unexpected events
- Management of distractions and interruptions within the working environment and inherent to every project.

First impressions of the "buffering method" to provide extra (safety) time and increase the confidence level of duration estimates, are that they *should* prove sufficient. However, as described in the previous section, this added time buffer is usually squandered because of a variety of reasons.

CCS addresses Parkinson's law with three main methodologies:

1. Eliminate deadlines for individual activities / tasks,
2. build the initial schedule with prudent *durations* which are *too rigid* to allow or promote a level of comfort which in turn leads to distracted attention, and
3. ensure that management take on the responsibility of protecting the project due date by protecting their resources from disruptions, rather than troubling them with non-critical distractions.

According to the CCS methodology, the initial schedule must be constructed without any buffers. This relates to the duration that can be expected for an activity assuming a certain level of ***sustainable*** input to the task at hand. This particular estimated duration can of course, only have approximately a 50% level of confidence as an unexpected event can occur at any time and consequently necessitates a negation of praxis on a managerial level.

Although it should be endeavored to stay within the limits of these aggressive duration time lines, it should be remembered that the initial confidence level is only 50% *and in no way can* *or should they be viewed as obligations*. The appropriate approach would rather be to keep in mind that the activity will simply take, as long as it will take and in no way can practices revert back to "due date scheduling".

"The work will be done.. when the work is done.."

Aggressive scheduling in itself is only the beginning of the CCS methodology and adequate consideration must be given to the inevitable influences of Murphy's law – especially on the critical tasks within the project.

8.3.2 Buffer Management

As explained by Parkinson's law, the added time buffers are rarely utilized to their full potential as they are not implemented at the *critical points* of the project.

The only difference between the afore-mentioned duration estimates (given with a 50% confidence level) and those which provided a 90% confidence level, were the time buffers added. When considering this fact together with the concept that the only date of importance is the final completion date, the time buffer is added to the end of the project in totality, providing what is called, a "**project buffer"** and thereby increasing the confidence level (of the project as a whole) again to 90%.

This *Project Buffer* can also be reduced to less than the traditional amount awarded as the sum of the individual buffers form conventional scheduling. As the 50% confidence level of the individual tasks (of the critical chain) also point to finishing early half of the time – there is a statistical indication that buffers are not only used, but also **replenished.**

When focus is shifted onto the non-critical tasks, the same assumptions and methods apply: namely that safety time or "buffers" are only added at the end of the feeding chain (*feeding buffers)* thereby protecting the start of the critical chain activity. Even if the total feeding buffer is depleted, the worst case scenario will be that the project will start utilizing the project buffer. Essentially, the non-critical activities are two buffers away from affecting the final completion of the project.

There are four types of buffers applicable to CCS; each serving the common purpose of protecting the project and its undertaken final completion date: **Project Buffer:** the largest of the buffers, implemented to protect the final completion date; **Feeding Buffers:** Protect the critical chain itself by adding "safety" time to less critical activities; **Capacity Buffers:** Used to assist resource balancing – especially in multi-project environments; and **Resource Buffers:** Do not directly impact the lead time or scheduling of a project, but acts to alert resources of an impending need.

By tracking the expenditure (or perhaps replenishment) of the various buffers, they serve as an indication or alert that a possible crisis is looming.

Buffer Management serves as a measure of continuously aligning the project with its original undertaken completion date and quality. They are an indication of where corrective actions are needed, (and equally important, where they are not needed) in order to ensure that the non-critical tasks are maintained as such and that the critical chain, remain exactly that: critical.

8.3.3 Taking advantage of early finishes

In order to methodically increase the speed with which projects are completed, the advantage of the occasional early completion of an activity must be utilized. Resource scheduling and utilization must be balanced in order to make the most of the time gained of finishing a task early. Once again, the focus must be on the critical chain and the resources it needs to progress; if the critical chain resources are scheduled in such a manner that the critical resources are available, immediate advantage can be obtained from a preceding task finishing ahead of "schedule".

In order to achieve optimal scheduling of the critical resources, two steps must be taken:

- Determine the amount of notice a resource requires to finish up its tasks in order to be able to switch to the critical task if the preceding activity should finish early, and
- Obtain regular, intermittent updates on the time needed from the resources to complete its current activity.

By following the before-mentioned steps, the critical resource can then be notified when the estimated time needed by the preceding task to complete its current activity is equal to the amount of notice the resource needs to prepare to pick up the activity on its way. The shift is thus away from reporting on the completion progress of a project, and towards the time needed in order to complete the task.

8.4 Important descriptions and definitions:

CCS is essentially a culmination of theories that is known to most Planners and Managers. Before the workings and implementation of CCS can be fully explained, it is important to understand a few of the theories behind the system.

8.4.1 Critical Chain vs. Critical path

The Critical chain of a project consists of dependent activities that define **the minimum lead time** the project will encompass. The dependencies between the tasks are created when the first activity provides the output needed as an input to the next activity and/or when an activity has to wait for a resource that is being utilized by another activity.

The core to the Critical Chain lies in the fact that aspects such as the intrinsic instability and uncertainty of projects (probabilistic behavior) and also the human factor (how people respond to the way a project is managed) is taken into account. Identifying the critical chain is done by assembling a collection of activities with “aggressive but attainable” time estimations. *(Patrick, F. 1999)*

The main differences between the *critical chain and the critical path* can be summarized into two factors:

- The critical chain ends at the start of the project buffer *(see section 9.5)* whereas the conventional critical *path* extends to the full end of the project itself, and
- The *critical path* is often interpreted as the standard dependencies between activities and does not take the resources needed (and/or allocated) into consideration. Critical Chain is unambiguously defined as a set of activities that have been leveled (balanced) in terms of resources.

8.4.2 TOC: Theory of Constraints

Critical Chain Scheduling is based on the well known *Theory of Constraints* which was first introduced by Dr. Eliyahu Goldratt in his book *The Goal.* Theory of Constraints (TOC) is derived from the hypothesis that even the most complex systems are governed by only a few aspects or constraints.

By adequately identifying and managing these constraints, the limiting factors of a project or system can be mitigated to produce a more agile, reliable and balanced outcome.

In order to identify the constraint in the CCS system, it is important to first note that some projects can be handled singular, other organizations have multiple projects at any point in time.

In the case of a singular project with an outcome such as a new product or process to a client, the success of the project can be measured by profitability which, in all likelihood, will be increased if the project is completed in a timely fashion. To identify the constraints one must simply decide on which constraint or restrictive aspect is influencing the measured outcomes. The limiting factors are simply the work that must be completed in order to provide the client with a finished product which can be utilized. From this it can be derived that the critical chain of the project is its constraint.

In a Multi-project environment, the distinctive constraints are unsynchronized commencing of various projects without effective resource allocation and management. The solution originating from the Theory of Constraints is utilizing buffer management to schedule critical resources in order to balance the workload through prioritizing.

8.4.3 Multi-tasking wastes time

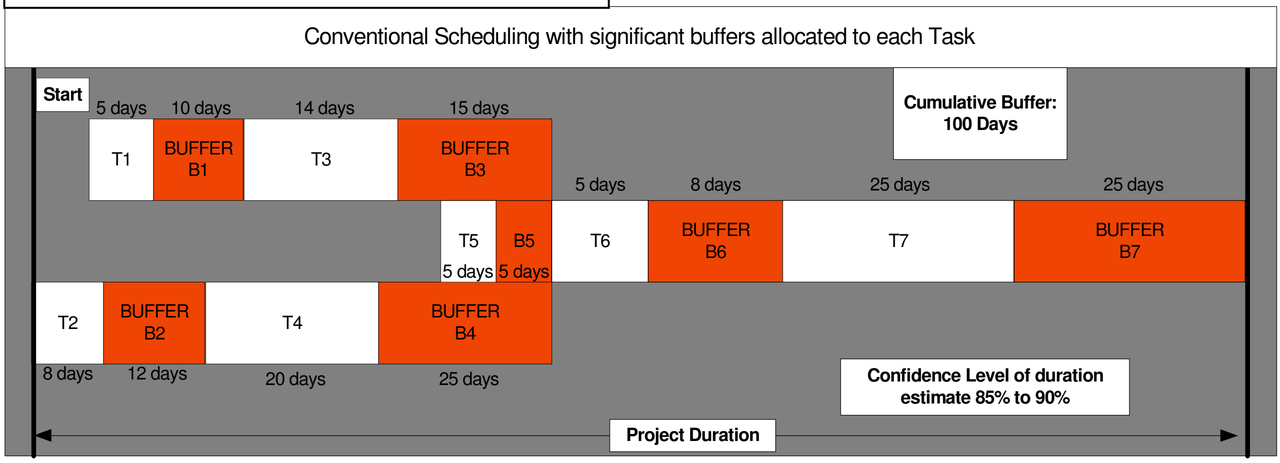
As *Megan Santosus* so eloquently stated, “Attention is a finite resource”. Various studies have shown that productivity of an employee, who is multi-tasking between four projects, is effectively 45% less productive than if the employee were focusing on only one project. Switching between projects may be possible if the tasks involved are simple, but the reality is simply that the pressure to remain competitive only increases complexity and multi-tasking problems arise when there is a need for innovative problem-solving.*(Santosus, M. 2003)*

From a practical, scheduling perspective, when multi-tasking, one task is idle while completing the next. Within the chains these tasks form, multi-tasking delays the start of the successor activity and time losses can amount to more than the sum of the time spent on the various projects. *(Patrick, F. 1999).*

8.5 CCS Example and explanation

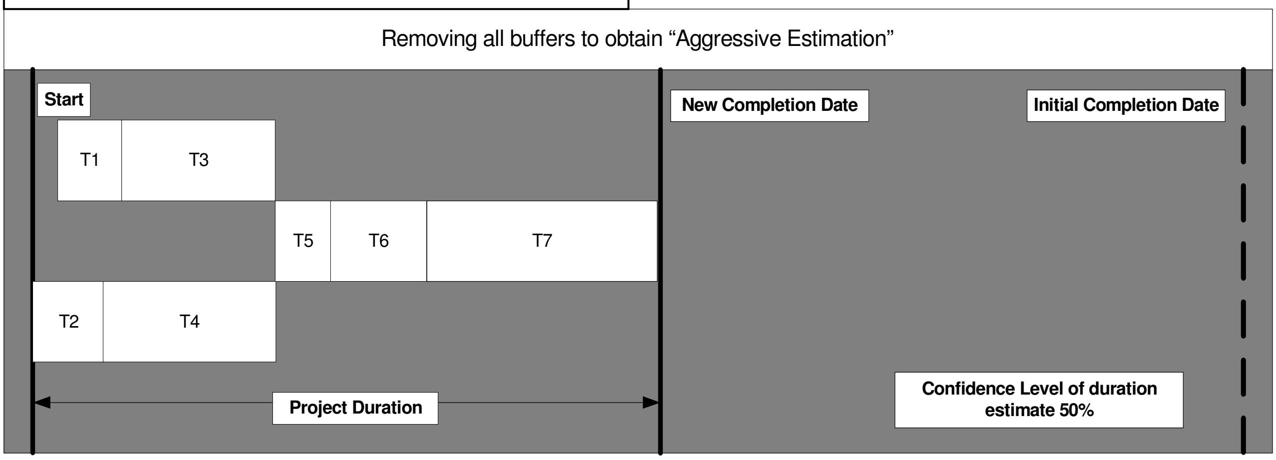
As briefly explained in the preceding sections, standard scheduling (and also MRP with buffered scheduling) places an amount of safety time or a buffer to protect every individual task. *(Figure 25)*. The following is a very simplified example of how Critical Chain scheduling can be utilized).

Figure 25: CCS application: Traditional scheduling



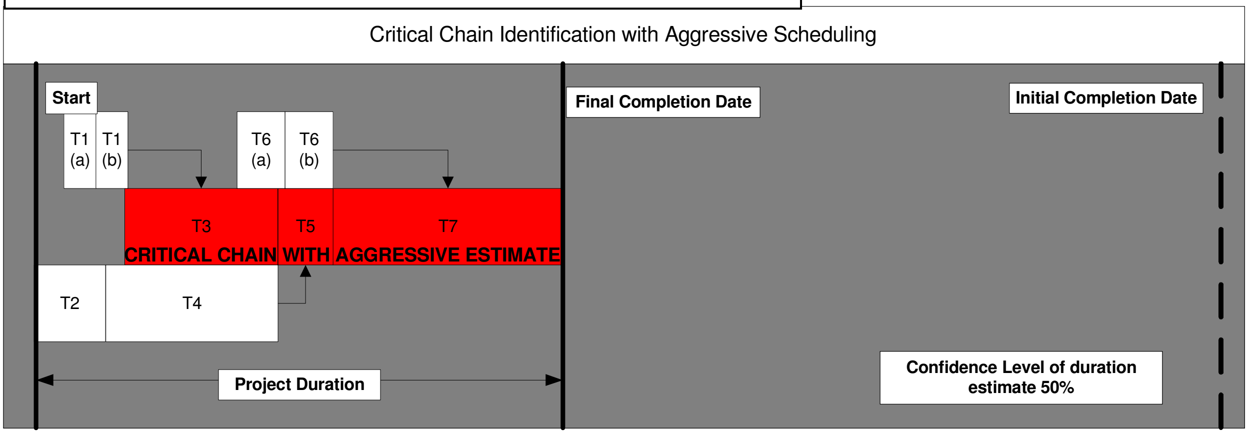
During the next step, aggressive time estimates are established by halving the original time durations. In this instance, the time durations are seen as the sum of the task itself and of the time buffer. *(Figure 26)*

Figure 26: CCS application: Aggressive Estimation



The critical chain is now identified with its auxiliary feeding chains by following the Theory of Constraints (*section 8.4.2*). *(Figure 27).*

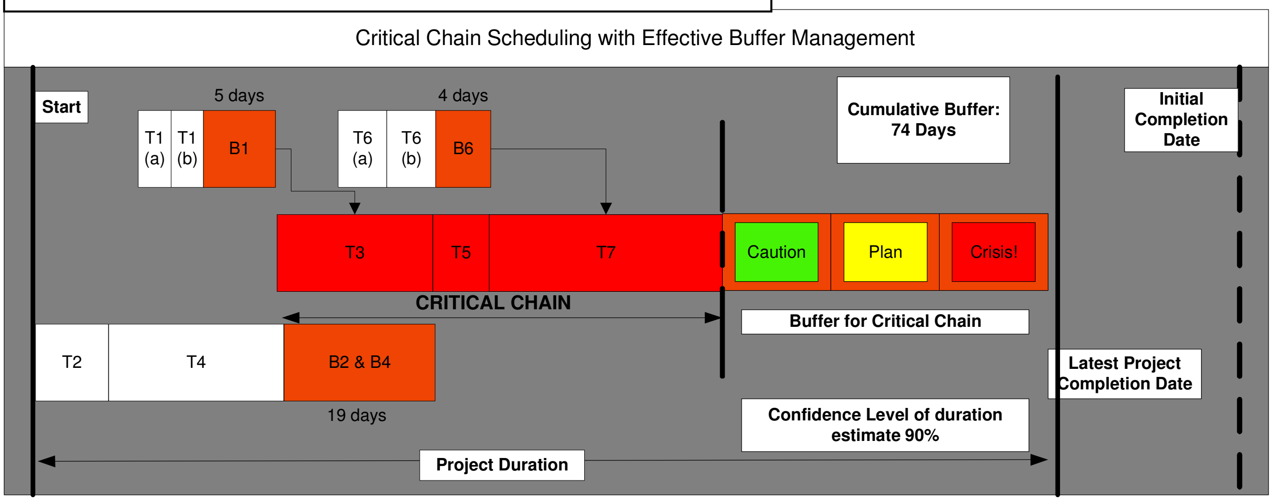
Figure 27: CCS application: Critical Chain Identification



Finally, the project and feeding buffers are added:

The general sizing and most basic approach to determine the size of the buffers is by using half of the difference between the sum of the original (longer) estimates and of the shorter, "aggressive" estimates. *(Figure 28)*

Figure 28: CCS application: Critical Chain Scheduling.



Further increased control over uncertainties and general schedule management lies in the green, yellow and red zones of the project buffer. As the sum of these zones equal the cumulative project buffer, different measures must be taken during each: Should the project start to consume the project buffer, it will start doing so within the green zone and management will be alerted to pay attention and that the situation may become more serious.

If buffer replenishment has not taken place and further problems arise (Murphy's law), the project will move on to consume the yellow zone of the project buffer which alerts management that action is needed to correct the course and protect the promised completion date of the project.

If mitigating plans fail, the project will move into the red zone and the situation will have reached a critical stage. It is within this stage that all and any measures must be taken protect the project from failure.

8.6 Application Areas

Critical Chain Scheduling (project management) has already been implemented in various industries. These include:

- Aerospace& Defense
- Agriculture
- Automotive
- Construction
- Electronics
- Engineering
- Food
- Healthcare
- Medicine
- Military
- Pharmaceuticals
- Quality systems
- Software Development

The US military has, quite successfully used Critical Chain Project Management to manage individual projects and project portfolios for low volume operations. CCS has also been implemented for projects such as the custom manufacturing of helicopters. *(Michael Pitcher, Operations Excellence: correspondence)*

8.7 CCS SOFTWARE

There are already various software packages that support Critical Chain Scheduling and although some are extremely capable to handle the complexity of Denel Dynamics' environment, it must be kept in mind that the company of somewhat 800 employees is already familiar with their own system, SAP.

Several functional requirements must be met by the chosen software for both the purposes of the project and the subsequent implementation of Critical Chain Scheduling at Denel Dynamics. These include (but are not limited to):

- The chosen software must be available within the financial constraints of the project
- Hardware specifications and requirements of the software must coincide with the hardware available.
- Clear and concise information must be forthcoming from the software in the form of reporting and monitoring functions when applying CCS.
- The software must be user-friendly without compromising functionality
- Integration options must be available to the current ERP system as inventory information and tracking (of both raw materials and work in progress) remains a priority.

8.7.1 Microsoft Project

More than 60% of project management software is based on Microsoft Project in all its various forms and versions. Although MS Project is a more than adequate tool for single project management, complications arise with project complexity and within multi-project environments.

Its background algorithms are still based on the 1960s MRP logic and although it can be utilized in the conventional scheduling processes, it may present significant problems when attempting to implement newer scheduling techniques such as CCS. *Process Quality Associates, 2006*

With "Add-on" software packages such as **CCPM+** and **CC-Pulse,** CCS or CCPM can be integrated using MS Project.

8.7.2 CC-Pulse as Microsoft Project "Add-in"

CC-Pulse is a software add-in module for Microsoft Project which integrates Critical Chain and buffer management concepts and allows the planning of production projects with aggressive time duration estimates. The software was designed by experienced critical chain managers, with extensive inputs from organizations utilizing critical chain scheduling.

CC-Pulse Software includes the following attributes:

- Eliminates resource contention by providing forward and backward scheduling,
- utilizes task and resource dependencies to identify the critical chain,
- calculates and incorporates drum feeding buffers, feeding buffers and the project buffer,
- enables continuous, integrated task tracking to identify buffer consumption and replenishment,
- provides integrated and real-time project update and resource reports,
- utilizes objective parameters for task level prioritization,
- enables user-specified parameters and inputs for task scheduling, and
- CC-Pulse is fully integratable into MS Project.

(Spherical Angle: CCS Software)

CC-Pulse has made the software available for use in this project and was utilized in the scheduling of the production of the rear fuselage of a missile. *(See section 10)*

8.7.3 Scitor PS Suite 8

The first problem with the implementation of Scitor is that is a stand-alone application which will be difficult to combine with currently used ERP systems. They do however have several fortune 500 companies as users despite being relatively unknown.

The software package has been designed for both older and CCS systems although application for CCS was designed as an "add-on" function. Scitor supports web-based inputs and can report live, real-time data to distributed project teams, clients and managers. *(Process Quality Associates, 2006)*

8.7.4 ProChain Solutions

ProChain solutions shows impressive technical expertise and was one of the first software packages specifically designed to assist with the implementation of CCS. They also provide assistance, not only with the software itself, but also with the physical implementation of the Critical Chain Scheduling methodology.

ProChain boasts clients such as governmental, federal and Fortune 500 companies and are showing a growth rate of 100% per year. The system is exclusively CCS and does not support any of the traditional scheduling methods.

The software is reputed to currently be the best on the market and also provides the most value for money. *(Process Quality Associates, 2006)*

Part D: Implementation, Results and Benefits

9 Implementation

Described in this section, will be the various steps to be taken for successful implementation of a Critical Chain Scheduling approach at Denel Dynamics. A smaller scale trial application of CCS will be conducted, illustrating the contrast between Conventional Scheduling (current approach) and Critical Chain Scheduling (Proposed approach). Results pertaining to the specific needs of Denel Dynamics and originating from both techniques will be listed and compared.

9.1 Scheduling: Rear Fuselage

9.1.1 Overview and parameters

The subsystem of a missile rear fuselage (*as modeled in the BOM in the Addendum A)* will be scheduled according to conventional MRP methodologies (as is currently used by Denel Dynamics) and its results will be contrasted to the outcomes of Critical Chain Scheduling procedures as is suggested by this project.

The controlled parameters within the scope of this project, assumes *ideal circumstances* regarding purchased items involved in the production of the rear fuselage. A new BOM (Bill of Materials) was thus constructed *(See Addendum B and C)* showing only the **in house production items** as the focus of the project.

The software to be used for modeling the scheduling schematic will mainly be *MS project.* Several sophisticated software packages for Critical Chain Scheduling exist but due to the financial limitations of the project, less known software packages will be utilized. For the purposes of Critical Chain Scheduling, the additional software of ***CC-Pulse*** will be used as an “add-on” feature to MS project. *(Also see section 8.7 on CCS Software and section 8.7.2 on CC-Pulse)*

Additional considerations include:

- the production of the rear fuselage of a missile will be managed as a product on its own (not a sub-system),
- production will be regarded as a *single project environment* and simultaneous and/or staggered approaches for batch production (multi-level project environments) will not be considered at this time,
- resources have been divided into the real-time average usage of *ten work centers* and are described as "WC 1….WC10" and the applicable work center will be listed with every activity on the schedule schematic,
- work centers will be regarded to have a 100% utilization factor and detail levels within the work centers themselves will not be considered,
- resource balancing will play a role – especially in CCS application although the current MRP methodology assumes infinite capacity and does not take resource conflictions into account,
- time durations for conventional scheduling includes buffered time and is thus at a 90% confidence level,
- *the length of a typical production run duration at Denel Dynamics ranges between 18 months and 30 months depending on the product, possible complications, customized items etc. Full implementation and production tracking will not be performed due to this project's time constraints,*
- in accordance to circumstances and limitations in Denel Dynamics' current environment *(section 6.3)* the conventional (MRP) schedule will not be simulated as rescheduling and adequate tracking / monitoring is not possible at this time,
- the Critical Chain Schedule will be simulated according to parameters and scenarios most frequently observed at Denel Dynamics – however these parameters are estimations,
- additionally for CCS Scheduling:
    - Aggressive duration estimates are defined as *task durations without any time buffer added,*
    - the *Critical Chain* is the series of events constrained by either resource conflictions and/or specific task dependencies and is determined by the CC-Pulse Software and does not include the project buffer, and
    - buffer allocation is calculated by CC-Pulse software and is indicated in the task list and added as dependencies in the schedule,

9.1.2 Conventional MRP Schedule: Rear Fuselage

MS Project is built on MRP theories and assumptions and is thus suitable to model the schedule according to conventional MRP techniques. The software (MS Project) will at this stage be used as is and without any add-in software. Both schedules will be modeled on the adapted BOM which has been modified to focus only on **in-house production items** as is shown in *Addendums B* and *C.*

Duration estimates are provided with a 90% confidence level *(section 8.2.1)* and are used as input along with the various task dependencies. As discussed in *Section 6.2,* Conventional MRP logic – and the specific application thereof currently in use by Denel Dynamics -adds buffered time to **every** task and assumes *infinite capacity:* resource contentions are not taken into account.

This translates into a schedule as is shown in *Addendum D* with total project duration of **429 days** and consisting of **115** separate tasks and milestones. As discussed in *section 6.3,* the production project rarely finishes by its originally scheduled due date which point to inconsistencies in the scheduling of the project and thus also in the subsequent execution thereof.

An important factor to consider regarding the estimation of 429 **days**, is that resource contentions have not yet been taken into account and should production follow this schedule, complications are imminent. With resource conflictions balanced and leveled, the production schedule estimate is extended to **776 days** as the over-allocated resources are now spread out and are assigned to finish their respective tasks before moving on to the next activity. *(Addendum E).* This now serves as an illustration of the schedule that will be followed and utilized according to **current** procedural methods. *(Also see sections 6.1, 6.2 and 6.3).*

9.1.3 Critical Chain Schedule: Rear Fuselage

The proposed solution is the implementation of Critical Chain Scheduling in an attempt to reduce lead times and work towards consistently reaching the project due date. **CC-Pulse** software is now installed and added to MS Project to provide the required Critical Chain Scheduling functionality.

Critical Chain Scheduling methodology is now followed, *(as described in section 8.5)* and the schedule is constructed from the same BOM as was used in section 10.1.2 *(shown in Addendum B).*

CCS scheduling firstly starts with determining the applicable ***aggressive duration estimates*** – *(Section 8):* time duration estimates **with no buffered time allowed**. These estimates are given with a 50% confidence level. Next, resource contentions are eliminated and utilization of the various work centers (resources) are balanced and scheduled to ensure that no work center is given too many tasks which could lead to time disruptions and unforeseen complications.

The **critical chain** is then identified by the CC-Pulse software by identifying the various task and resource dependencies. These critical chain tasks are then listed as activities that are constrained to start at a specific time and will remain the focus of the project throughout its execution.

Feeding Buffers are then added only at the applicable intervals where activities "feed" the critical chain *(section 8.3.2).* The project buffer is then added **at the end of the critical chain** as a last measure of protection against uncertainty.

Through this method of scheduling, the estimated project duration has been reduced to **627days** which already amounts to a reduction of **20%**. It should also be noted that the number of tasks or activities has now increased to **153** as the various buffers are added as dependent tasks. This also relates to *section 6.2.2.2* which notes that instead of simplifying the number and complexity of the dependencies in the Schedule and BOM, it may be more advantageous to instead *add* levels and items –as was done by the scheduling methodology in this instance.

If the project is monitored and managed adequately, the consumption of the project buffer can be avoided, reducing the project duration to only **503 days;** a massive reduction of **35%.** *(See Addendum F for Schedule Schematic with Critical Chain and various buffers).*

When compared to the schedule generated in the previous section, a significant reduction in the duration estimate of the project has already been achieved. Through the unique methodology of Critical Chain Scheduling, the probability of completing the project within this (reduced) estimation is also far greater.

9.1.4 Critical Chain Schedule: Project Tracking

A hypothetical simulation of the schedule was performed, simulating the progression of the project and the ensuing buffer consumption and replenishment. *Please note that the dates are in the future in order for the scheduling input parameters of CC-Pulse to be valid and executable.*

The project was taken to a completion stage of 405 days bringing the project date to 2 January 2012 and having an estimated remaining duration of 222 days. The project schedule which incorporates various stages of task completion percentages and their respective effects on the execution of the remaining activities are shown in Add*endum G*.

The *Buffer Report* generated by CC-Pulse, *(Addendum H),* demonstrate that even after several tasks had encountered delays, it is still highly probable that the project can be completed by its originally scheduled due date. This is mainly because of the feeding and project buffers still remaining along with the utilization of possible early finishes and the subsequent buffer replenishment that will take place.

There are however only 35 days of the original 125 days left of the project buffer which puts the project buffer status at *Yellow,* notifying management that the project is at risk of not meeting its deadline and that appropriate action(s) must be taken or contingency plans be set in motion *(also see section 8.5).*

CC-Pulse now re-calculates the placement of buffers and assists in rescheduling the remaining tasks in order to increase the probability of still finishing the project by its due date. The full project report (at the date of 2 January 2012) can be seen in *Addendum I.*

The *Collective Project Report* serves as a status update and lists summary information pertaining to all tasks: Expected and Actual Start dates, Duration estimation until completion, as well as the "safe" or buffered duration within which every specific task is expected to be completed in order to still reach the **original** due date of the Project.

9.2 Measurable Results

From the scheduling methodologies utilized in Section 9.1 the following is a summary of the results obtained:

Conventional MRP Methodology: *(section 9.1.2)*

- Conventional MRP methodology provided a project duration estimate of **429 days** when assuming infinite capacity
- The number of tasks remained consistent at 115 as duration estimates already contained buffered time
- A project duration estimate of **776 days** were obtained once resources had been leveled – providing a more accurate projection.

In accordance with circumstances as are described in sections 6.2 and 6.3, it may be assumed that by following these scheduling techniques, the duration estimate of 776 days is the best possible outcome of the project and that the probability of this estimate is extremely low.

Critical Chain Scheduling *(sections 9.1.3 and 9.1.4)*

- The Critical Chain Scheduling method provides a project duration estimate of **627 days,** which translates into a reduction of **20%** in the total project duration.
- The *Critical Chain duration estimate* (without the project buffer) is **503 days,** which in turn translates into a **35%** reduction in the total project duration.
- The number of tasks actually increases to 153 as various buffers are added into the schedule with their respective dependencies *(section 6.2.2.2).*
- The added number of tasks relates to the theory that the addition of tasks may be more advantageous than the removal thereof and/or the flattening of the BOM.
- Rescheduling and monitoring as the project progresses can be done without difficulty – keeping the project continuously up to date regardless of the number or complexity of disruptions that may occur.
- Sufficient warning with regards to project buffer consumption was given with status updates providing chances for the implementation of contingency plans

9.3 CC-Pulse Analysis and Software Implementation

Measured against the functional requirements set in *section 8.7, CC-Pulse software add-in for MS project* proved to be an intelligent scheduling program capable of various project calculations, providing sufficient tracking and monitoring functions.

Continuous project updates were available whilst focus remained on the "only date that matters – the project due date" by tracking the project buffer consumption and replenishment.

- Integration options must be available to the current ERP system as inventory information and tracking (of both raw materials and work in progress) remains a priority.
- Denel currently makes use of the **SAP ERP** and **MRP** systems in order to perform inventory tracking and scheduling
- SAP does however have various MRP modules and before completely new software is introduced, the available MRP modules must be investigated and considered for their applicability to Critical Chain Scheduling
- CCS software like **Scitor PS Suite 8** and **ProChain Solutions** both provide expertise consultancy in addition to the sophisticated software packages on offer and will provide even more comprehensive capabilities than those provide by software such as **CC-Pulse** and **CCPM+.***(Section 8.7)*

9.4 Steps to Critical Chain Scheduling

It is important to understand that the critical elements of implementing CCS lies not only with the methodologies and technologies *but (more so) with management and their negation of praxis.* It is not only the processes that must be adjusted and improved, but also management and the leadership characteristics they will require for the task.

The implementation of Critical Chain Project Management / Scheduling is simply a "disciplined approach to managing work we already do" - *Woeppel, M. (2009)* and should be treated as such.

New Actions are added:

- Different time duration estimates – and ways to reach them
- A change in Buffer Management – more strategic placement
- Focusing project execution effort on project completion dates rather than task due dates

Inadequate actions are removed:

- Avoid and/or eliminate multi-tasking to focus on prompt project execution
- Eliminate pressured environments and “panicked”, quality-compromised tasks
- Do not plan without considering resource utilization and constraints.

The Implementation of Critical Chain Scheduling can be categorized in three main activities:

1. **Planning**
2. **Execution**
3. **Monitoring**

These three main activities will be customized for Denel Dynamics’s needs and unique environment and input from various successful case studies will also be considered.

9.4.1 Planning

The planning phase is already underway and involves the following activities:

- A core group within Operations Management division is assembled consisting of experienced, senior planners, configuration management staff and the IT department (to provide software support and input).
- The software available *(as mentioned in section 8.7 and 9.3)* will be explored further with regards to complete CCS packages as well as SAP functionalities and possible integration.
- Past projects were examined to identify trends as to time (buffer) wastage, multi-tasking and project overruns.
- Management is deliberating on factors which cause and influence multi-tasking in an attempt to establish single project environments more frequently.
- A relatively simple project was selected in order to demonstrate the methodology of Critical Chain Scheduling and also as a small scale test project.*(section 9.1 and 9.2)*The applicable results are stated in *section 9.2* and serves as a trial implementation and test for the implementation of Critical Chain Scheduling.

9.4.2 Execution

- Selected Management staff will be trained as to the concepts and methodology of CCS
- Management will also be encouraged to make the paradigm shift from set due date scheduling to project completion date focus and will be briefed on how staff must be supported accordingly. *(Section 8.3.1)*
- Multi-tasking identified during the Planning phase will be eliminated where possible.
- Software developed and/or acquired during the planning phase will be implemented and integrated with the current ERP system if the integrated functionality is required.
- Resource allocation and balancing will be given extra attention with regards to the scheduling process as well as during the monitoring phase.
- A conscious effort will be made to utilize early finishes by keeping the focus on the critical chain, its resources and constraints.
- Full scale implementation will be done on new projects only and projects in progress will be completed based on their initial schedule and the techniques applied

9.4.3 Monitoring

This last category is perhaps the most important from a management perspective. It will be their task to train the staff and assist with the paradigm shift away from individual task due dates.

- The project itself will be monitored according to CCS: regular reports and updates will be made available as to the status of a task.
- Constant feedback and communication must be maintained with staff to ensure a smooth transition to CCS.
- Buffer Consumption and replenishment must be adequately monitored.
- Continuous feedback from resources will be required - with regards to the time needed to complete current tasks, amount of warning needed before other, priority tasks can be executed as well as updates on available and required resources and their current percentage utilization.
- Contingency plans must be set in place should the project start consuming the project buffer in any of the three zones. *(Section 8.5)*

10 Case Studies

The following is an abbreviated list of companies who experienced similar problems to Denel Dynamics before implementing Critical Chain Scheduling. Results after implementation are consistent in their nature of reducing lead times, complexity and cost while increasing reliability and improving alignment between planning and execution phases.

- **Airgo Networks:** The Pioneer and worldwide leader in Multiple Input Multiple Output (MIMO) technology.

  Execution Problem: Long cycle times: From first silicon to production for first generation was 19 months.

  CCS Results: Cycle time from first silicon to production reduced to 8 months

- **Amper Programas:** A leader in its market: with three lines of business – Information and Communications Systems for the armed forces, avionics and radio navigation aids for aviation.

  Execution Problem: On time deliveries were very rare and the status of projects was continually obscure.

  CCS Results: Better visibility and prioritization within projects, leading to a 500% increase in on – time delivery.

- **Chrysler:** Major automotive producer with a wide variety of products and a workforce of approximately 384,723 employees.

  Execution Problem: Cycle time for prototype was 10 weeks with high overtime costs and crisis management.

  CCS Results: 10% decrease in overtime charges and delivery performance increased by 83% with little to none crisis management needed.

- **US Air Force Operational test & Evaluation Center:** (AFOTEC) is responsible for testing under operationally realistic conditions, new systems being developed for Air Force and multi-service use.

  Execution Problem: On-time delivery was unknown due to constantly moving due-dates. 18 projects delivered in a six –month period.

  CCS Results: On time delivery increased to 75% with cycle times reduced by 30%. Twenty-six projects were completed in six months. *(Realization: Project Execution Management)*

- **US Naval Aviation Depot, Cherry Point:** Provides extensive maintenance and engineering support to Navy and Marine Corps aviation, including armed services.

  Execution Problem: Throughput of 23 per year; average turnaround time for H-46 aircraft was 225 days and for the H-53 aircraft, 310 days.

  CCS Results: Turnaround time for the H-46 aircraft was reduced to 167 days (25% reduction achieved despite an increasing scope of work). Turnaround time for the H-53 aircraft was reduced to 180 days – 41% reduction. The depot experienced an overall 70% reduction in its backlog.

11 Benefits of CCS

The case studies briefly discussed in *section 10,* clearly indicate that Critical Chain Scheduling has great improvement potential and emphasizes the need for more advanced scheduling techniques in especially the aerospace and defense industry.

In any manufacturing process, it is expected to have some discrepancies between resources planned vs. the resources available during execution. These discrepancies or deficiencies in planning must be overcome by actions in execution. *(Miles, 2009)*

One substantial advantage of Critical Chain Scheduling is that less intricate analysis of task data is needed. Because of its unique buffer management system and the distinction from critical path to *critical chain*, the occasional consumption of a time buffer will likely be replenished at another stage.

Buffer management in itself is also a much simpler task than with methods such as “earned value Management (EVM)” and adds benefits to the bottom line without creating more effort than is saved.

Below is a table listing the contrasting aspects of CCS in terms of traditional scheduling and also mention some of the other important advantages CCS can provide – especially for Denel Dynamics. *(Section 6.3 discusses the problems Denel Dynamics face and their subsequent need for the improvements CCS can provide as is listed in Table 4)*

Table 4: Contrasts and benefits of CCS *(PQA, 2006)*

Conventional Scheduling	Critical Chain Scheduling	Advantages of CCS
Uses the longest time estimate from the two-point probabilistic curve.	Uses the mean of the statistical time duration estimate as the task duration.	• More consideration is given to resource utilization and consumption • True factors consuming available time durations are more evident • More speed can be achieved with less pressure on staff and resources.
Time buffers are added to all individual tasks / activities	Project completion date is protected by a *project buffer* as well as by strategically placed *feeding buffers.*	• Strategic placement of safety time avoids wastage and adequately protects the most important date: the project completion date. • Prompt delivery can be made without compromised quality.

Progress of individual tasks is stressed.	Emphasis is placed on total project progress.	• Holistic viewpoint of the project at all times. • Eliminates micro-management • Disruptions are identified early and focus is placed on the critical elements of the problem – enabling faster solutions.
Emphasis on starting tasks as soon as possible	Emphasis on commencing a task when it *needs* to start.	• Emphasis stays on critical chain tasks and not shifted erroneously to non-critical tasks. • Better resource utilization and management for faster project completion.
Specific dates for starting and ending a task.	Task to start as soon as its predecessor is completed and conclude tasks as quickly as possible – no individual due dates.	• Relay race methodology is used and emphasis is placed on the "handover" of one task to the next. • More information is available on the status of a task; in terms of time duration needed to complete task, notice needed to start another task or whether the task has just completed. • Less multi-tasking, more focus.
Accepts resource conflicts as unavoidable.	Focuses on resource balancing and leveling to allow for early finishes.	• Critical resources are easily identified and incorporated into the schedule accordingly. • Focus remains on the critical resource to ensure the critical chain of the project is not disrupted or unduly delayed. • Constraints are carefully monitored and managed.
Accepts multi-tasking as the norm	Uses priorities to avoid and/or eliminate time consuming multi-tasking.	• Staff are trained to identify disruptive and unnecessary multi-tasking • Multitasking is avoided and/or eliminated to reduce collective project lead times. • Consumed project lead time can by reduced by up to 40%
Manages uncertainty and instability by re-scheduling and placing pressure on individual tasks.	Uses effective buffer management (consumption and replenishment) to absorb the impacts of uncertainty.	• Project priorities and focal points remain reliable and consistent. • Pressure on staff is reduced, which increases quality. • Project schedules and their priorities stay consistent. • Greater organizational stability is achieved. • Morale and productivity is boosted as frustration lowers and goals are accomplished.
Inter-task relationships established by *"impromptu"* scheduling decisions.	Inter-task relationships are established according to physical, critical chain scheduling requirements.	• Stagnant thinking is replaced by innovative strategies. • Agility and adaptability both within the company and its environment is increased • Competitive advantage gained through implementation of better strategies and a shift away from an aged praxis.

12 Challenges Encountered

There are a few relatively evident challenges that have surfaced during the course of the project and its implementation.

The first of which is the software integration and the possible pitfalls with costing. Because of the project's constraints, not all available Critical Chain Software could be explored and therefore further study will be needed especially with regards to the current ERP system, SAP. Should adequate software be acquired and/or developed, it will prove an extremely arduous and costly task to implement throughout Denel Dynamics – especially when considering their affiliations with other companies and within their own divisions.

This can potentially also result in confusion and increased pressure on employees and planners instead of alleviating it. Further investigation into the software possibilities and capabilities is thus paramount in order to apply the alternative which will be least invasive in an already complex environment.

The most prominent challenge however, is management itself. Experienced planners and those knowledgeable in the industry tend to "keep to what they know" and become, in a sense, comfortable in their positions and duties even if those duties place them under unnecessary pressure.

In *IBM*'s latest *Global CEO study* entitled: "*The Enterprise of the Future"*, it found that a rapidly increasing gap is emerging between the need for change CEOs acknowledge, and the extent to which they are prepared to implement the said changes.

> *"We have seen more change in the last ten years than in the previous 90" – Ad J Scheepbouwer, CEO, KPN Telecom*

Globalization has rapidly increased the need to remain competitive and the only way companies can (continually) accomplish this, is by changing and growing along with customer and market demands. The IBM study found that those companies and CEOs who were more open to change, were the clear outperformers. *IBM, 2008*

The greatest challenge with the implementation of Critical Chain Scheduling, is not the technology itself, but the paradigm shift that must occur at a management level before changes can be made in the hierarchy of the company and their work methodologies.

13 Conclusion

Critical Chain Scheduling is an innovative tool which holds great promise for those companies willing to make the change. This is illustrated not only by the **time reduced at initial scheduling** but also in the execution of the unique Critical Chain Scheduling methodology which avoids safety time wastage and employs buffer management to enable replenishment. (*Sections 9.1 and 11)*

Numerous Case studies (*see abbreviated examples in section109)*have proven the extensive benefits of this emerging methodology which has the potential to make an enormously positive impact on Denel Dynamics.

The core problems faced by Denel Dynamics, (project overruns, unreliable project and task duration estimates, and inadequate mitigation of uncertainty factors) are symptoms of the greater problem of **diverging planning and execution phases**. This divergence, in turn, is caused by the erroneous application of a scheduling technique (MRP) in an environment in need of a more innovative approach and the obvious conflicts arising from attempting to implement a *push system* scheduling methodology in a *pull-system* environment. *(Section 6.2.2)*

The trial implementation of Critical Chain Scheduling already indicates that these core problems can be addressed through the implementation of Critical Chain Scheduling and its inherent characteristics. Full validation and testing procedures cannot be performed at this stage as the duration of an average production run at Denel Dynamics range between 18 months and 30 months and thus fall beyond the scope of the project.

From the results obtained from the smaller scale trial implementation, *(as stated in sections 9.1 and 9.2),* and in accordance to the case studies presented in *section 10,* the following outcomes can however be extrapolated with regards to the implementation of Critical Chain Scheduling at Denel Dynamics:

(Please refer to section 6 on Denel and section 6.3 on the specifics regarding the problems to address, and also section 8.3, 9.1, 9.2, 10 and 11 for Critical Chain Methodology, results, case studies and benefits respectively)

- Better lead times can be achieved with increased reliability in the frequency with which project due dates are met.*(Sections 8.3, 9.1, 9.2, 10 and 11)*
- Better quality projects executed in a more timely fashion
- Alleviated pressures on staff and resources
- Cost savings due to better management and time utilization
- Less multi-tasking, more focus
- Continued / gained competitive advantage due to innovative strategies.
- Agility and flexibility in response to both Parkinson's law and Murphy's law.
- Addresses rescheduling for better management and monitoring

Ultimately, the implementation of Critical Chain Scheduling, will result in better alignment of the planning and execution phases through innovative scheduling and effective buffer management.

Despite various challenges *(section 12)*, CCS is a relatively simple methodology to implement with the most difficult responsibilities falling on management and not the technology or the implementation thereof.

After implementation is completed, Denel Dynamics will be able to benefit from some of the key advantages and improvements CCS provides such as improved project lead times, balanced resource utilization and better mitigation of uncertainty factors which will all translate to the project's bottom line *(section 11)*.

Perhaps the greatest advantage of CCS is that it addresses not only the technical side of scheduling, but also the human factors involved, and attempts to smooth this interface.

With every project completed with the assistance of Critical Chain Scheduling, the transition will be smoother and the benefits greater, adding to cumulative output enhancement and as inherent outcome, smoother integration and closer working environments between the various system resources.

Through improved scheduling, the very need for *alignment between planning and execution* phases will be reduced as the factors which stood as the cause for the divergence, *(as discussed in section 6)* will be mitigated early on – not only keeping track of the final project due date, but also focusing on the influencing factors which can potentially extend this date.

The idea is to work smarter, not harder.

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15ADDENDUM

A: BILL OF MATERIALS (BOM) for Rear Fuselage (section 1 to 3)

B: BILL OF MATERIALS for Rear Fuselage: Internal Production items only

C: BOM List: In-House Production Items

D: Schedule: Conventional MRP Schedule – no resource balancing

E: Schedule: Conventional MRP Schedule – With resource balancing

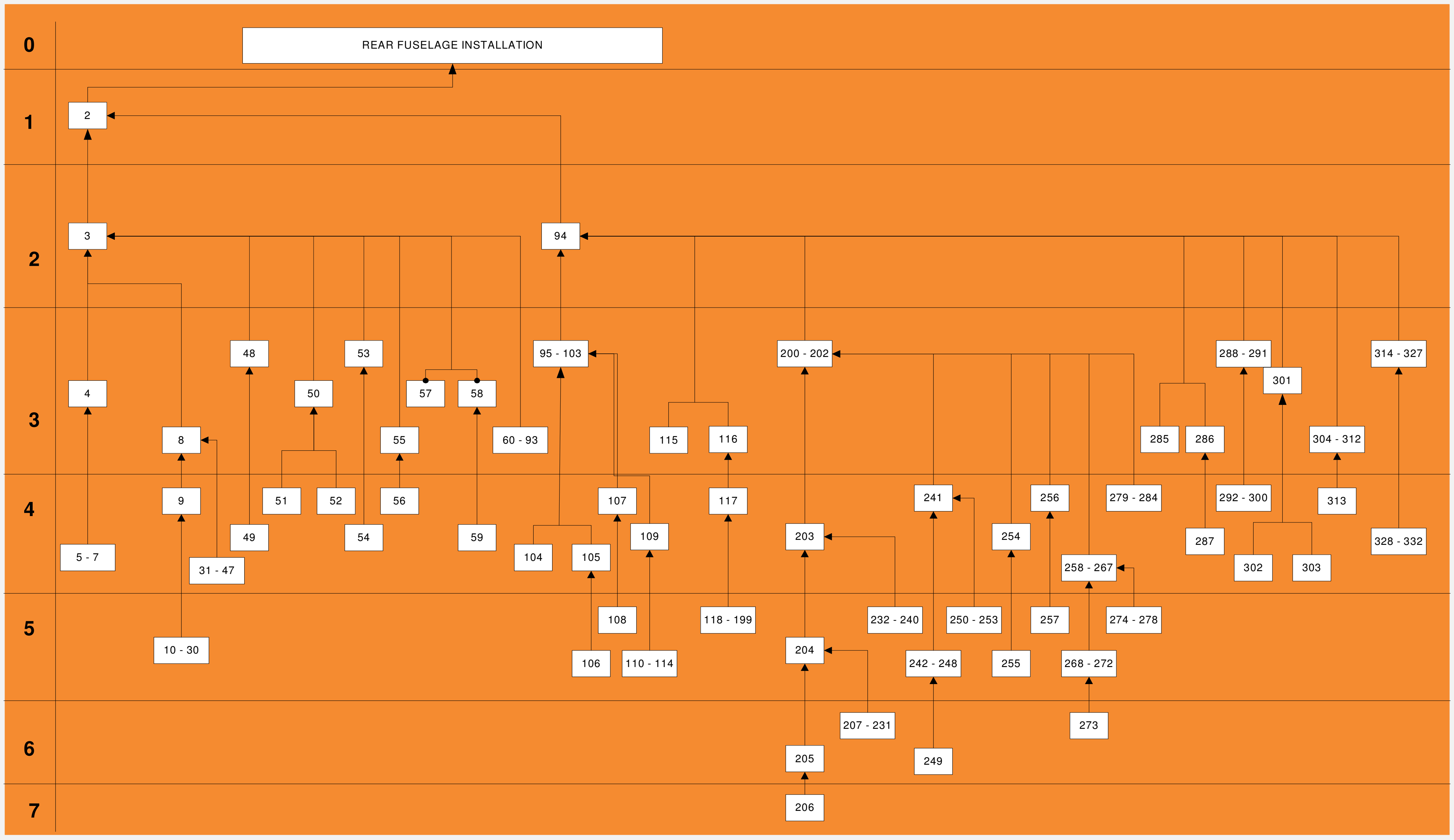
F: Schedule: Critical Chain Schedule – Buffer management and resource balancing applied

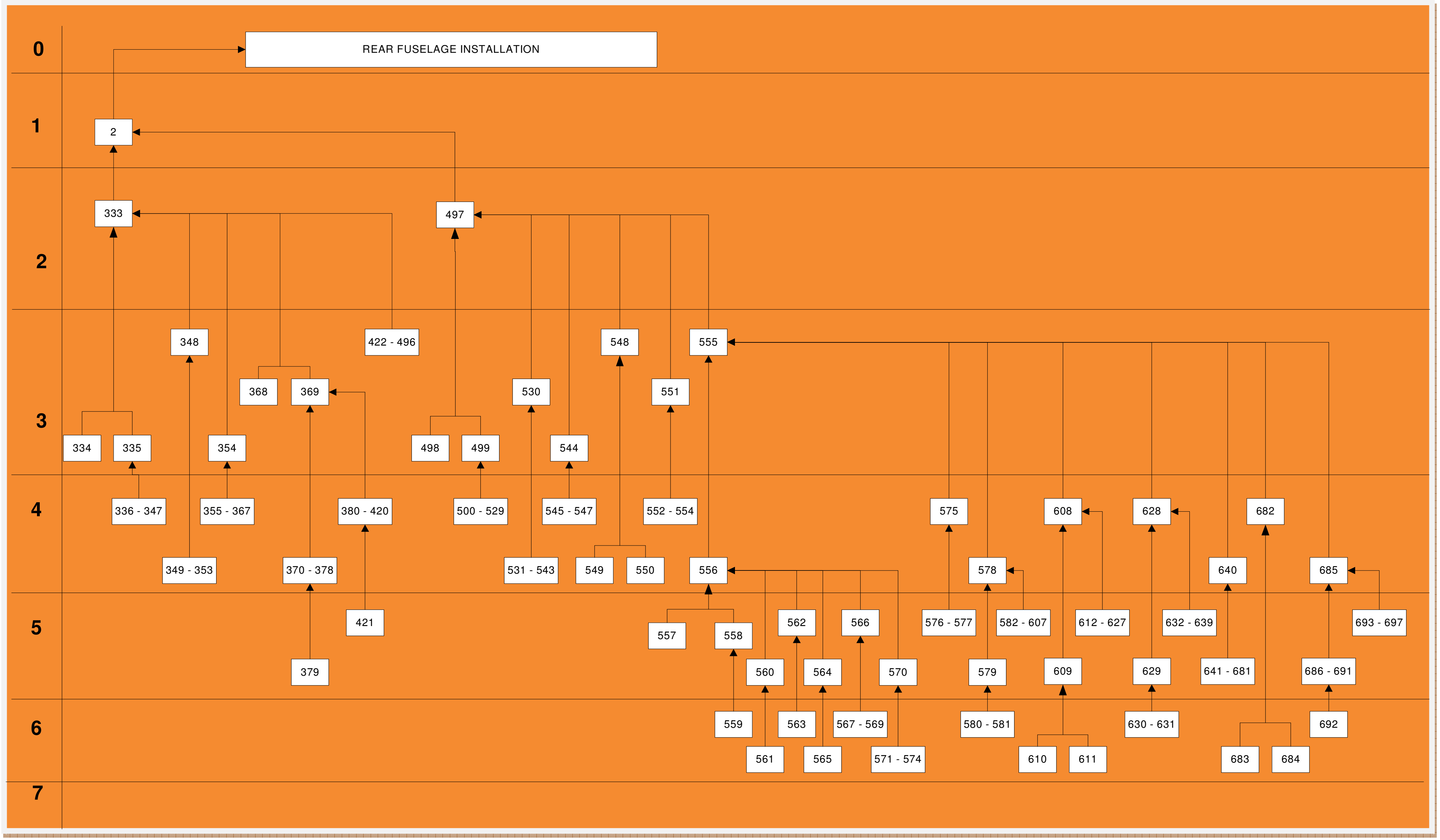
G: Schedule: CCS – Project tracking and buffer usage

H: Buffer Report for CCS Schedule tracking

I: Project Report for CCS Schedule tracking

Addendum A: BOM of Rear Fuselage




0
1
2
3
4
5
6
7
REAR FUSELAGE INSTALLATION
2
333
497
348
422 - 496
548
555
368
369
530
551
334
335
354
498
499
544
336 - 347
355 - 367
380 - 420
500 - 529
545 - 547
552 - 554
575
608
628
682
349 - 353
370 - 378
531 - 543
549
550
556
578
640
685
421
557
558
562
566
576 - 577
582 - 607
612 - 627
632 - 639
693 - 697
379
560
564
570
579
609
629
641 - 681
686 - 691
559
563
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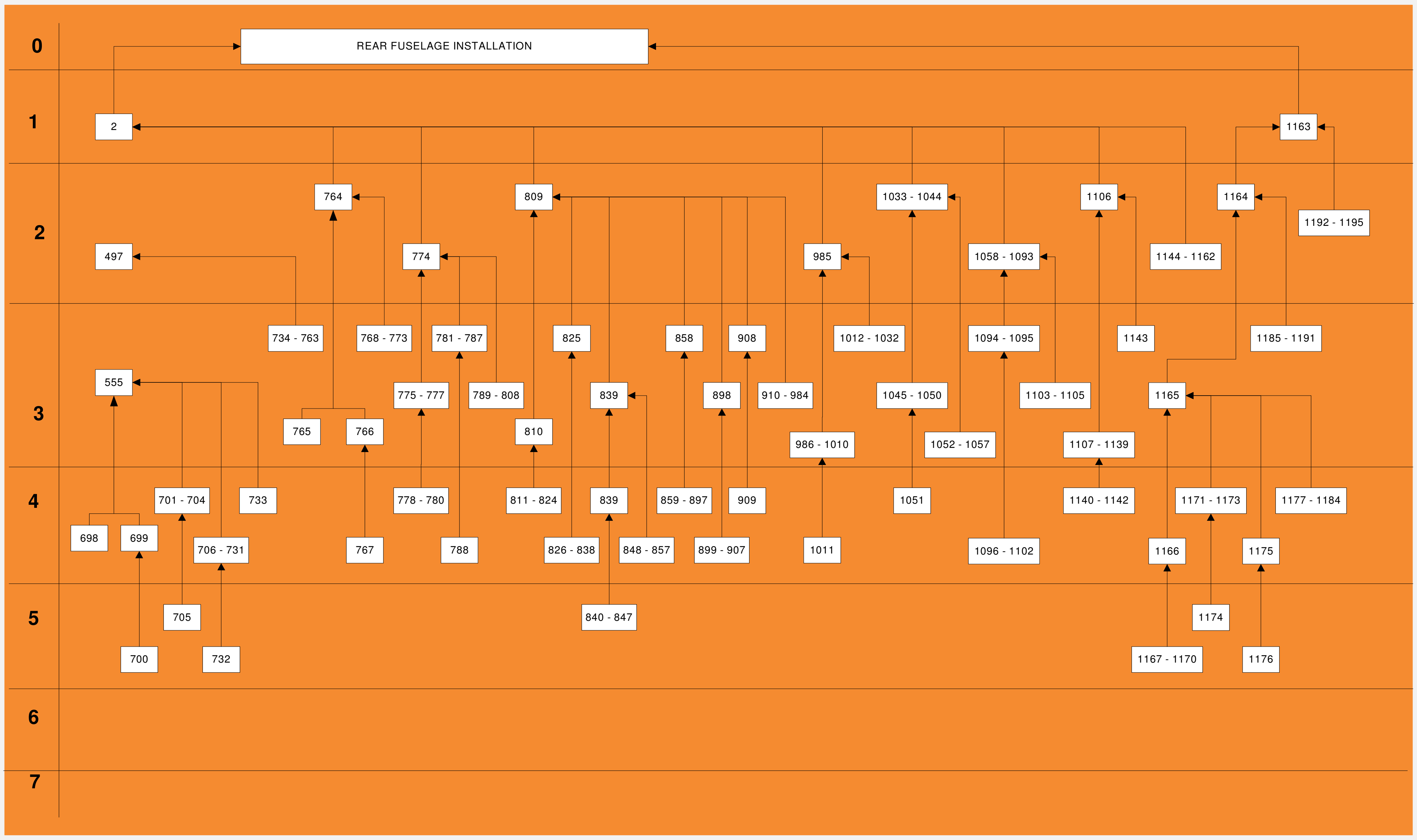
580 - 581
630 - 631
692
561
565
571 - 574
610
611
683
684



0
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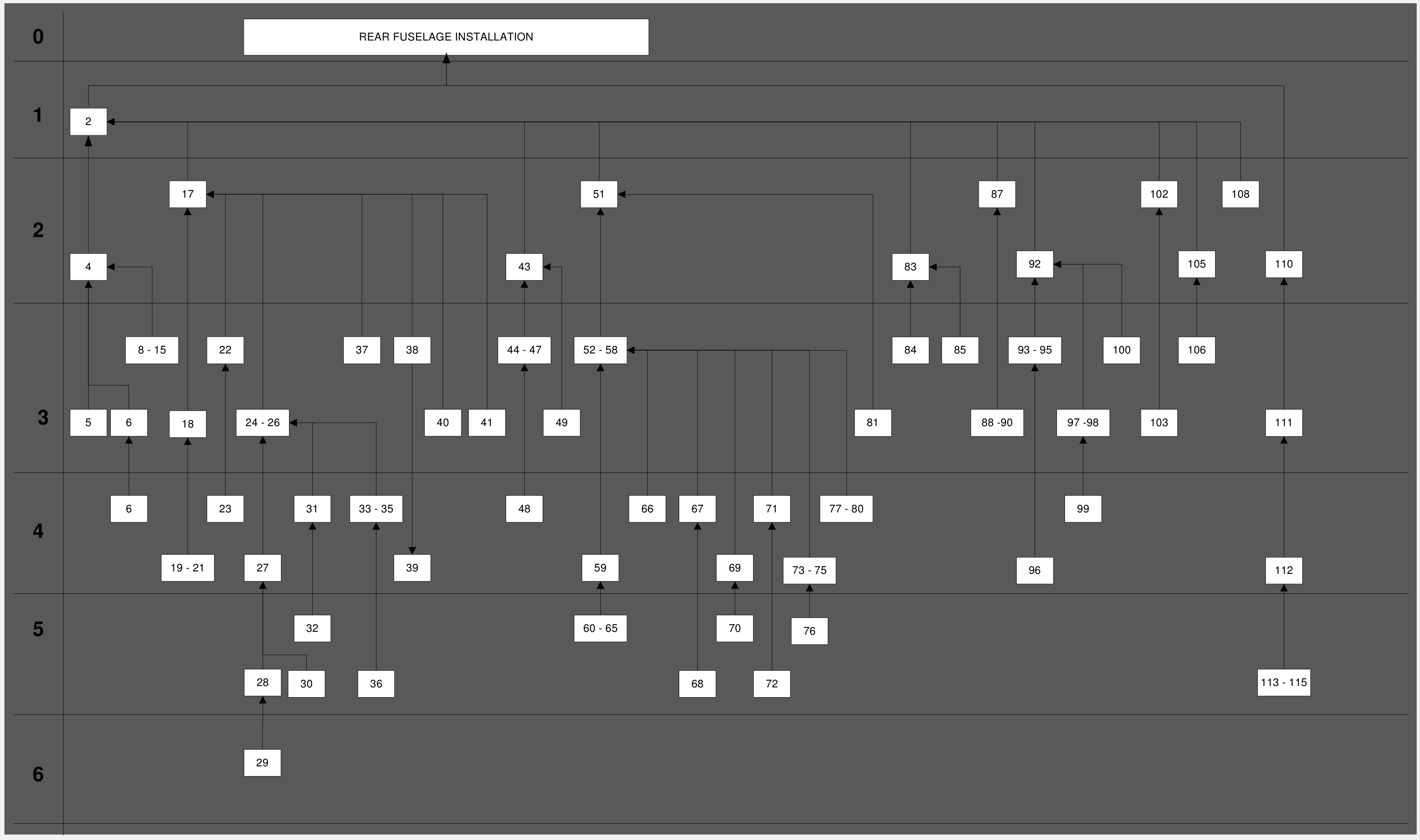
2
3
4
5
6
7
REAR FUSELAGE INSTALLATION
2
1163
764
809
1033 - 1044
1106
1164
1192 - 1195
497
774
985
1058 - 1093
1144 - 1162
734 - 763
768 - 773
781 - 787
825
858
908
1012 - 1032
1094 - 1095
1143
1185 - 1191
555
775 - 777
789 - 808
839
898
910 - 984
1045 - 1050
1103 - 1105
1165
765
766
810
986 - 1010
1052 - 1057
1107 - 1139
701 - 704
733
778 - 780
811 - 824
839
859 - 897
909
1051
1140 - 1142
1171 - 1173
1177 - 1184
698
699
706 - 731
767
788
826 - 838
848 - 857
899 - 907
1011
1096 - 1102
1166
1175
705
840 - 847
1174
700
732
1167 - 1170
1176

Addendum B: BOM: In-house Production Items



Addendum C: BOM List: In-house items

Level		Material	Description	Qty	Parent	Lead Time
0	1	27-000000-80	REAR FU INSTALALTION	1		10
	1		Level 1 milestone			
A	2	28-000000-81	REAR FU	1	10461-20000/1	100
	3		Level 2 milestone			
B	4	26-000000-89	POWER S	1	10461-20010/1	0
C	5	21-000000-85	BASE PL	1	10461-23000/1	0
C	6	23-000000-87	CHASSIS	1	10461-23000/1	45
D	7	26-000000-90	TRANSFO	1	10461-23020/1	45
C	8	20-000000-34	PCB ASS	1	10461-23000/1	15
C	9	28-000000-41	PCB ASS	1	10461-23000/1	15
C	10	23-000000-59	PCB ASS	1	10461-23000/1	0
C	11	25-000000-61	PCB ASS	1	10461-23000/1	0
C	12	20-000000-55	BRACKET	1	10461-23000/1	145
C	13	23-000000-4	SHEET;	0.01796	09546-004/2	0
C	14	28-000000-91	COVER	1	10461-23000/1	30
C	15	20-000000-57	SPACER,	3	10461-23000/1	145
	16		Level 2 milestone			
B	17	21-000000-58	COMMAND	1	10461-20010/1	90
C	18	25-000000-66	PCB ASS	1	09548-000/18	2
D	19	22-000000-61	SPACER	3	09548-500/4	0
D	20	20-000000-61	TOROID	1	09548-500/4	8
D	21	23-000000-62	TRANSFO	1	09548-500/4	5
C	22	24-000000-65	RX uP C	1	09548-000/18	0
D	23	22-000000-63	PCB ASS	1	09548-455/1	20
C	24	21-000000-62	PCB ASS	1	09548-000/18	20
C	25	24-000000-26	WASHER;	24	09548-000/18	45
C	26	24-000000-66	RF SECT	1	09548-000/18	30
D	27	27-000000-82	IFE	1	09548-630/3	90
E	28	21-000000-77	SUBSTRA	1	10461-21005/2	20
F	29	22-000000-78	SUBSTRA	1	10461-21020/1	20
E	30	24-000000-80	PCB ASS	1	10461-21005/2	0
D	31	27-000000-66	FILTER	1	09548-630/3	90
E	32	21-000000-59	CONNECT	2	09548-360/2	60
D	33	20-000000-63	CABLE 5	1	09548-630/3	45
D	34	21-000000-64	CABLE 6	1	09548-630/3	5
D	35	23-000000-66	VCO ASS	1	09548-630/3	20
E	36	20-000000-62	SCREW	2	09548-690/1	35
C	37	25-000000-67	CABLE 1	1	09548-000/18	0
C	38	27-000000-64	IF AMP	1	09548-000/18	5
D	39	25-000000-64	PCB ASS	1	09548-030/6	90
C	40	22-000000-60	PCB ASS	1	09548-000/18	0
C	41	25-000000-62	SCREW M	6	09548-000/18	60
	42		level 2 milestone			
B	43	21-000000-35	TAIL UN	1	10461-20010/1	5
C	44	23-000000-38	TAIL FU	1	05063-24000/3	20
C	45	24-000000-68	LOOM AS	1	05063-24000/3	20
C	46	28-000000-43	WIRING	1	05063-24000/3	15
C	47	21-000000-36	TAILPLA	1	05063-24000/3	0

D	48	27-000000-70	GEAR 10	1	05063-24010/3	45
C	49	21-000000-7	TAIL UN	1	05063-24000/3	0
	50		level 2 milestone			
B	51	28-000000-92	TV TX S	1	10461-20010/1	20
C	52	21-000000-86	PCB ASS	1	10461-28000/2	0
C	53	22-000000-87	MOTHERP	1	10461-28000/2	30
C	54	25-000000-90	HARNESS	1	10461-28000/2	45
C	55	26-000000-91	CABLE A	1	10461-28000/2	5
C	56	27-000000-92	CABLE A	1	10461-28000/2	0
C	57	28-000000-93	CABLE A	1	10461-28000/2	60
C	58	20-000000-86	SOLID S	1	10461-28000/2	0
D	59	27-000000-11	PCB ASS	1	10461-28100/1	10
E	60	28-000000-12	INDUCTO	1	02595-42350/4	10
E	61	20-000000-5	INDUCTO	1	02595-42350/4	10
E	62	21-000000-6	INDUCTO	1	02595-42350/4	10
E	63	22-000000-7	TRANSFO	1	02595-42350/4	16
E	64	23-000000-8	TRANSFO	1	02595-42350/4	10
E	65	26-000000-11	TRANSFO	1	02595-42350/4	10
D	66	28-000000-13	PCB ASS	1	10461-28100/1	15
D	67	26-000000-92	PCB ASS	1	10461-28100/1	15
E	68	28-000000-94	PCB ASS	1	10461-28110/4	0
D	69	22-000000-89	PCB ASS	1	10461-28100/1	15
E	70	23-000000-90	PCB ASS	1	10461-28120/3	0
D	71	26-000000-93	PCB ASS	1	10461-28100/1	0
E	72	27-000000-94	PCB ASS	1	10461-28130/2	0
D	73	21-000000-89	PCB ASS	1	10461-28100/1	0
D	74	23-000000-91	CABLE A	4	10461-28100/1	0
D	75	25-000000-73	FILTER	1	10461-28100/1	0
E	76	28-000000-76	MOUNTIN	4	09551-210/1	45
D	77	21-000000-5	CONNECT	2	10461-28100/1	52
D	78	25-000000-9	PILLAR	2	10461-28100/1	45
D	79	25-000000-91	WALL	1	10461-28100/1	0
D	80	23-000000-89	ABSORBE	1	10461-28100/1	0
C	81	24-000000-7	PCB ASS	1	10461-28000/2	130
	82		Level 2 milestone			
B	83	23-000000-77	DUMMY M	1	10461-20010/1	20
C	84	24-000000-78	PLATE,	1	10461-20050/2	30
C	85	25-000000-75	WEIGHT	1	10461-20050/2	20
	86		level 2 milestone			
B	87	26-000000-76	REAR FU	1	10461-20010/1	30
C	88	23-000000-75	CLAMPIN	10	09572-010/8	5
C	89	21-000000-72	SCREW	1	09572-010/8	30
C	90	24-000000-75	RING FR	1	09572-010/8	45
	91		Level 2 milestone (85)			
B	92	26-000000-82	SAD	1	10461-20010/1	60
C	93	24-000000-83	DRIVER	1	10461-22000/2	60
C	94	23-000000-81	HARNESS	1	10461-22000/2	15
C	95	25-000000-87	FUZE MO	1	10461-22000/2	0
D	96	20-000000-83	HARNESS	1	10461-22080/2	5
C	97	20-000000-82	PCB ASS	1	10461-22000/2	60
C	98	26-000000-83	TIMER A	1	10461-22000/2	30
D	99	21-000000-79	SPINDLE	1	10461-22010/2	0
C	100	28-000000-89	CONNECT	1	10461-22000/2	30

	101		Level 2 Milestone			
B	102	26-000000-81	WIRING	1	10461-20010/1	20
C	103	23-000000-78	CONNECT	1	10461-20210/1	10
	104		Level 2 milestone			
B	105	20-000000-32	FIN ASS	1	10461-20010/1	0
C	106	21-000000-33	FIN ASS	1	05063-20040/1	45
	107		Level 2 milestone			
B	108	24-000000-36	ALTERNA	1	10461-20010/1	45
	109		Level 1 milestone			
A	110	26-000000-94	CONTAIN	1	10461-20000/1	120
B	111	28-000000-96	CONTAIN	1	10461-81200/1	0
C	112	22-000000-91	CONTAIN	1	10461-81210/1	0
D	113	26-000000-75	CONTAIN	1	10461-81250/1	0
D	114	23-000000-92	SEAL, L	1	10461-81250/1	0
D	115	24-000000-93	SEAL, B	1	10461-81250/1	0

Addendum D: Conventional MRP Schedule – no resource balancing

See section 9.1.2

(4 Pages)

Addendum E: Schedule: Conventional MRP Schedule – With resource balancing

See section 9.1.2

(4 Pages)

Addendum F: Schedule: Critical Chain Schedule – Buffer management and resource balancing applied

See section 9.1.3

(7 Pages)

Addendum G: Schedule: CCS – Project tracking and buffer usage

See section 9.1.4

(7 Pages)

Addendum H: Buffer Report for CCS Schedule tracking – (See section 9.1.4 and Addendum G)

Task ID	Buffer Name	Buffer End Date	Expected Finish	Buffer Length (days)	Buffer Guide (days)	Protection Ratio	Buffer Left (days)	Chain Left (days)	Check Task
3	Project Buffer	Mon 2/11/13	Fri 11/16/12	125.38	-41.78	**0.59**	35	222.5	25
21	FB: PCB ASS	Wed 6/22/11	Thu 1/5/12	3	-144.25	**-47.08**	0	3	108
17	FB:CABLE 5	Thu 10/6/11	Wed 1/18/12	7	-81.45	**-10.64**	0	7	25
67	FB: CABLE A	Mon 5/7/12	Fri 2/3/12	4.03	61.7	**1**	4.03	5.5	25
126	FB: SAD	Tue 6/19/12	Wed 3/21/12	30.81	33.42	**1.04**	30.81	37	25
124	FB: SAD	Tue 6/19/12	Mon 3/12/12	30.02	41.01	**1.1**	30.02	31	25
128	FB: SAD	Tue 6/19/12	Fri 3/9/12	30.41	41.62	**1.12**	30.41	35	25
38	FB: REAR FU	Fri 9/7/12	Mon 7/2/12	56.79	-7.76	**1.4**	56.79	85	25
100	FB: REAR FU	Fri 9/7/12	Tue 7/3/12	24.5	23.5	**1.96**	24.5	37.5	25
97	FB: SOLID S	Mon 6/18/12	Mon 3/5/12	11.05	63.99	**3.17**	11.05	12	25
122	FB: SAD	Tue 6/19/12	Fri 2/10/12	15.03	77.6	**5.1**	15.03	16	25
50	FB: TAIL UN	Thu 8/30/12	Fri 3/30/12	23.09	86.14	**5.21**	23.09	29	108
54	FB: TAIL UN	Thu 8/30/12	Mon 3/12/12	24.17	99.06	**5.26**	24.17	32	108
56	FB: TAIL UN	Thu 8/30/12	Mon 3/12/12	24.17	99.06	**5.26**	24.17	32	108
116	FB: REAR FU	Mon 9/3/12	Fri 4/27/12	20	71.63	**5.33**	20	20	25
107	FB: REAR FU	Fri 9/7/12	Mon 5/28/12	15.81	58.82	**5.73**	15.81	20	108
114	FB: REAR FU	Mon 9/3/12	Fri 5/18/12	15	61.63	**6.11**	15	15	25
52	FB: TAIL UN	Thu 8/30/12	Wed 3/14/12	22.02	99.11	**6.18**	22.02	23	108
93	FB: SOLID S	Mon 6/18/12	Wed 12/7/11	22	116.48	**6.29**	22	22	92
9	FB: REAR FU	Fri 9/7/12	Tue 5/22/12	11.23	67.41	**6.56**	11.23	16	25
119	FB: SAD	Tue 6/19/12	Thu 1/26/12	15	88.13	**6.88**	15	15	35
68	FB: SOLID S	Mon 6/18/12	Fri 2/3/12	4.03	91.7	**8.44**	4.03	5.5	25
95	FB: SOLID S	Mon 6/18/12	Fri 1/27/12	11.05	90.09	**8.97**	11.05	12	25
140	FB: FIN ASS	Tue 7/31/12	Mon 1/23/12	15	120.73	**9.05**	15	15	139
62	FB: SOLID S	Mon 6/18/12	Thu 1/19/12	11.04	96.59	**9.75**	11.04	11.9	25
90	FB: SOLID S	Mon 6/18/12	Fri 1/20/12	7.07	98.76	**9.85**	7.07	8	108
131	FB: SAD	Tue 6/19/12	Fri 1/20/12	10	97.23	**10.72**	10	10	73
82	FB: SOLID S	Mon 6/18/12	Thu 1/26/12	5.66	96.58	**11.53**	5.66	8	108
151	FB: Level 1	Fri 11/16/12	Tue 9/11/12	4	44	**12**	4	8	108
59	FB: TAIL UN	Thu 8/30/12	Fri 3/30/12	5	104.63	**12.73**	5	5	25
88	FB: SOLID S	Mon 6/18/12	Wed 2/1/12	7	90.73	**13.96**	7	7	139
85	FB: SOLID S	Mon 6/18/12	Wed 1/11/12	7	105.73	**14.68**	7	7	84
143	FB: REAR FU	Fri 9/7/12	Tue 2/14/12	2	145.73	**73.87**	2	2	135
136	FB: WIRING	Wed 9/5/12	Tue 2/7/12	2	148.73	**76.37**	2	2	135
80	FB: SOLID S	Mon 6/18/12	Thu 3/1/12	1	75.73	**76.73**	1	1	45
78	FB: SOLID S	Mon 6/18/12	Tue 1/3/12	1	117.73	**117.73**	1	1	77

Addendum I: Project Report for CCS Schedule tracking – (See section 9.1.4 and Addendum G)

Task ID	Task Name	Resource Name	Actual Start Date	Expected Start Date	Duration (days)	RemainDuration(days)	Safe Duration: (days)
1	REAR FU	WC 2		Fri 9/7/12	50	50	100
6	TRANSFO	WC 3		Tue 1/31/12	5	5	10
7	CHASSIS	WC 3		Wed 3/14/12	10	10	20
8	POWER S	WC 4		Mon 5/21/12	1	1	2
10	SHEET;	WC 2		Fri 5/18/12	1	1	2
11	BASE PL	WC 5		Thu 2/9/12	1	1	2
12	PCB ASS	WC 7		Wed 2/8/12	2	2	4
13	PCB ASS	WC 9		Fri 3/2/12	2	2	4
14	PCB ASS	WC 6		Thu 1/26/12	7	7	14
15	PCB ASS	WC 8		Mon 1/23/12	7	7	14
16	SPACER,	WC 4	Thu 6/30/11	Thu 6/30/11	70	7	140
18	BRACKET	WC 10		Fri 1/13/12	75	75	150
20	CONNECT	WC 2	Thu 12/30/10	Thu 12/30/10	30	3	60
24	IFE	WC 4	Tue 3/29/11	Tue 3/29/11	45	4.5	90
25	SUBSTRA	WC 5	Mon 2/21/11	Mon 2/21/11	10	0.2	20
27	PCB ASS	WC 4		Mon 3/5/12	40	40	80
29	RF SECT	WC 2		Fri 2/10/12	15	15	30
30	CABLE 6	WC 5		Tue 1/24/12	5	5	10
31	VCO ASS	WC 6		Thu 1/12/12	10	10	20
33	SPACER	WC 2	Wed 9/28/11	Wed 9/28/11	2	1	4
34	PCB ASS	WC 3		Fri 1/27/12	2	2	4
35	TRANSFO	WC 3	Fri 9/30/11	Fri 9/30/11	2	0.6	4
36	TOROID	WC 5	Mon 9/26/11	Mon 9/26/11	4	3.6	8
37	COMMAND	WC 1		Mon 5/7/12	40	40	80
39	RX uP C	WC 8		Fri 1/20/12	1	1	2
40	PCB ASS	WC 9	Mon 11/14/11	Mon 11/14/11	10	9	20
41	PCB ASS	WC 10	Tue 11/8/11	Tue 11/8/11	10	8.5	20
42	CABLE 1	WC 5		Tue 1/31/12	1	1	2
43	PCB ASS	WC 8		Wed 1/4/12	1	1	2
44	IF AMP	WC 1		Mon 4/30/12	5	5	10
45	SCREW M	WC 9	Mon 7/11/11	Mon 7/11/11	30	12	60
48	TAIL UN	WC 10		Thu 8/30/12	2	2	4
49	WIRING	WC 6		Wed 3/21/12	7	7	14
51	TAILPLA	WC 3		Tue 3/13/12	1	1	2
53	TAIL FU	WC 7		Mon 2/27/12	10	10	20
55	LOOM AS	WC 6		Mon 2/27/12	10	10	20
57	GEAR 10	WC 1		Thu 1/26/12	22	22	44
58	TAIL UN	WC 2		Fri 3/23/12	5	5	10
61	PCB ASS	WC 2	Wed 9/21/11	Wed 9/21/11	1	0.9	2
63	MOUNTIN	WC 5	Mon 8/22/11	Mon 8/22/11	22	11	44
64	INDUCTO	WC 2	Mon 9/26/11	Mon 9/26/11	2	1.9	4

	HARNESS	WC 3		Tue 2/7/12	22	22	44
66	PCB ASS	WC 7		Thu 2/2/12	2	2	4
69	TRANSFO	WC 4		Wed 1/18/12	2	2	4
70	TRANSFO	WC 5	Fri 9/30/11	Fri 9/30/11	2	0.4	4
71	INDUCTO	WC 3		Tue 1/3/12	2	2	4
73	TRANSFO	WC 1	Thu 9/15/11	Thu 9/15/11	7	3.5	14
74	CABLE A	WC 3		Thu 3/8/12	2	2	4
75	PCB ASS	WC 3		Mon 3/12/12	1	1	2
76	SOLID S	WC 10		Mon 6/18/12	1	1	2
77	WALL	WC 8		Tue 1/3/12	1	1	2
79	ABSORBE	WC 9		Thu 3/1/12	1	1	2
81	PCB ASS	WC 1		Fri 1/20/12	4	4	8
83	PCB ASS	WC 2		Wed 1/11/12	4	4	8
84	PCB ASS	WC 6		Tue 1/3/12	7	7	14
87	PCB ASS	WC 7		Tue 1/24/12	7	7	14
89	PCB ASS	WC 8		Wed 1/11/12	7	7	14
91	PCB ASS	WC 2		Tue 1/10/12	1	1	2
92	CONNECT	WC 4		Mon 11/7/11	22	22	44
94	CABLE A	WC 3		Thu 1/26/12	1	1	2
96	FILTER	WC 4		Fri 3/2/12	1	1	2
99	TV TX S	WC 2		Tue 6/19/12	10	10	20
101	CABLE A	WC 5		Mon 2/6/12	1	1	2
102	MOTHERP	WC 2		Fri 3/2/12	15	15	30
103	CABLE A	WC 10		Mon 5/7/12	30	30	60
104	PCB ASS	WC 9	Mon 8/22/11	Mon 8/22/11	60	21	120
106	DUMMY M	WC 2		Mon 5/21/12	5	5	10
108	WEIGHT	WC 2		Mon 12/19/11	10	10	20
109	PLATE,	WC 1		Mon 2/27/12	15	15	30
112	REAR FU	WC 10		Mon 9/3/12	2	2	4
113	CLAMPIN	WC 2		Fri 4/27/12	15	15	30
115	SCREW	WC 2		Fri 3/30/12	20	20	40
118	PCB ASS	WC 3		Thu 1/5/12	15	15	30
120	SAD	WC 10		Tue 6/19/12	30	30	60
121	TIMER A	WC 2		Thu 2/9/12	1	1	2
123	HARNESS	WC 5		Fri 3/9/12	1	1	2
125	DRIVER	WC 6		Mon 3/12/12	7	7	14
127	FUZE MO	WC 5		Fri 3/2/12	5	5	10
129	SPINDLE	WC 2		Thu 1/19/12	15	15	30
130	CONNECT	WC 1		Fri 1/6/12	10	10	20
132	HARNESS	WC 4		Fri 1/20/12	30	30	60
134	WIRING	WC 10		Wed 9/5/12	2	2	4
135	CONNECT	WC 7		Mon 2/6/12	2	2	4
138	FIN ASS	WC 10		Tue 7/31/12	22	22	44
139	FIN ASS	WC 7	Tue 6/14/11	Tue 6/14/11	50	15	100
142	ALTERNA	WC 7		Mon 2/13/12	2	2	4
145	SEAL, L	WC 2		Tue 7/3/12	2	2	4
146	CONTAIN	WC 7		Thu 7/5/12	2	2	4
147	CONTAIN	WC 3		Wed 6/20/12	2	2	4
148	SEAL, B	WC 3		Fri 6/22/12	2	2	4
149	CONTAIN	WC 8		Mon 7/9/12	2	2	4
150	CONTAIN	WC 10		Fri 9/7/12	2	2	4