

# **Design of a Model to assist in aligning Engineering and Production environments**

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## Executive summary

### *Background of project problem*

Denel Dynamics is a well established Engineering company, specializing in the design and production of missile and other electronic devices. Development at Denel Dynamics continuously improves along with new technology, knowledge and resources. It is extremely difficult to align development and production in such a dynamic environment. This implies that planning for future production, while still designing and developing the product, is almost impossible. The result of this could cause unstable planning baselines leading to waste of resources, labor and material. A solution to stabilize planning is urgently needed.

### *Goal and Scope of Project*

Denel Dynamics' aim is to make the interaction between the Engineering and Production Departments as effective as possible. The result would be improved future production planning and help managing the point in time to transfer the Bill of Materials, BOM, between departments. A model must be created which could contribute to the proposed solution. This will enable intelligent future production planning taking instabilities and risks from Engineering into account and managing part maturity to determine when a BOM could be transferred.

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## Abbreviations

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BL	Base Line
BOM	Bill of Materials
CM	Configuration Management
CRB	Change Review Board
DDI	Document Data Index
DEV	Development
DIR	Document Information Record
DV	Development Manager
ECN	Engineering Change Notification
ECP	Engineering Change Proposal
ECR	Engineering Change Request
ERP	Enterprise Resource Planning
FRACA	Failure Reporting Analysis and Corrective Action
HR	Human Resources
ISO	International Organization for Standardization
IT	Information Technology
IW	In work
MM	Material Master
MNF	Manufacturing
MPS	Master Production Schedule
MRP	Material Requirements Planning
PCMB	Product Configuration Management Board
PDI	Product Data Index
PDM	Product Data Manager
PM	Project Manager
PPS	Project Planning Schedule
PR	Problem Report
ProgM	Program Manager
PRR	Production Readiness Review
PS	Product Structures
Q	Qualify
QA	Quality Management
QC	Quality Control
RL	Release
SAP	System Application Products
SE	System Engineer
T&E	Test and Evaluate
TRB	Technical Review Board

## PART A

### 1. INTRODUCTION

Denel Dynamics is an established Engineering company specializing in the design and production of missile and other electronic devices. Denel Dynamics is a subdivision of Denel, a large company, working together with the military industries situated all over South Africa. Denel Dynamics does Engineering, Design and Manufacturing of very complex electronic devices and specialized mechanical components of high complexity. As the research and development at Denel Dynamics improves with new technology, knowledge and resources, the production requirements varies on a continuous basis.

### 2. BACKGROUND

The majority of Denel Dynamic's clients are from other countries and a portion from South Africa's own military. Contracts are exceptionally large and have long durations, up to 10 years. Denel Dynamics uses Systems, Applications and Products, SAP, as an Enterprise Resource Planning System, ERP, to integrate materials and resource planning over all the subdivisions in order to reach the goals and requirements for contracts. The three important planning subdivisions of Denel Dynamics are Finance, Production and Engineering Development. Finance and Production management is done directly according to SAP's standards. Development is planned and executed using a software system called Product Data Management Link, PDM Link.

### 3. CURRENT SYSTEM

When a contract is finalized and signed the Engineering Department starts to design and develop the product according to company’s policy and standards. When development nears completion a bill of materials, BOM, is generated and sent on to the Production Department. The Production Department immediately uses the BOM to start the crucial production planning on the Material Requirements Planning tool. Production planning consists of ordering the required materials and subassemblies from suppliers, manufacturing customized components and assembling parts with the allocated resources. The main concern is to be able to perform the whole process with a high standard of quality but within costs and schedule goals.

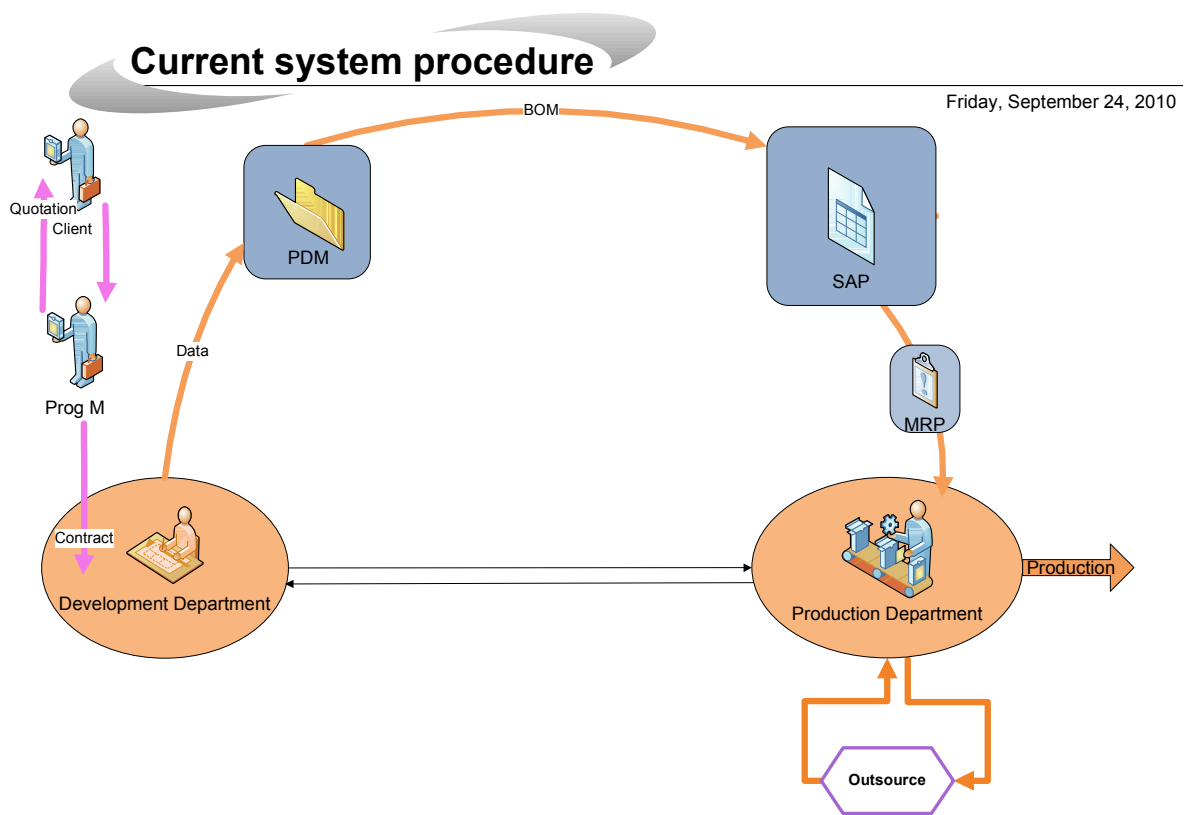


Figure 1



## 4. PROBLEM OUTLINE DESCRIPTION

To control the maturity of the engineering bill of materials, BOM, before sending it to MRP is inherently difficult with technical concerns and risk related to high complexity development. It is similarly difficult for the Production Planning department to assess the related maturity to a received BOM. This risk could lead to optimistic planning on both sides, Production and Engineering Development Departments, with high potential of resource waste during execution. Unplanned changes on the BOM due to late discovery of engineering problems could result in wrong parts being ordered, order modifications needed after material was already delivered, scrapping of material, production having to rework parts according to new specifications, etc.

The standard SAP planning module, MRP, does not cater for any uncertainties in the BOM. MRP rather assumes a very mature BOM which cannot be changed at all once planning starts. An immature BOM leads to continuous re-plan of production.

## 5. DENEL DYNAMICS USER REQUIREMENTS

Denel Dynamics aim is to make the interaction and information flow between the Engineering and Production Departments as effective as possible. The improved system must deliver integrated computerized communication, capable of processing data and displaying the required information to relevant departments. The result would be an improved interlinking Engineering Development and Production Department.

## 6. THE PROJECT AIM

The challenge is to find an intelligent planning solution to translate remaining engineering into future production planning. This must be without unacceptable delay but also not with unrealistic expectations on delivery schedules.

An accurate model must be designed that can translate engineering risk factors into sensible time adjustments of the standard MRP times. The solution aims to prevent planning variances that cause production adjustments and wastage of resources. The model must also be able to assist in determining the transfer point of a BOM between Engineering Development and Production.

## 7. LITERATURE REVIEW

### 7.1 Introduction

In the project report some new insight has been developed according to the project problem and aim. A literature review was conducted in order to support the newly developed insight in the design. The literature review aims to summarize and synthesize the relevant information to provide a solid background of the project.

### 7.2 Tools, methods and skills Discussed in the Literature review:

- **Probability Transition Model, (PTM)**
  - Markov Chains
  - Forecasting
  - Capability study
  - Decision Analysis
  - MATLAB (SOLVE)
  - Static Testing
  - Dynamic Testing
- **Product Data Management, (PDM)**
- **Material Requirement Planning, (MRP)**
- **Bill of Materials, (BOM)**

### 7.3 Content

#### 7.3.1 Probability Transition Model

##### Markov Chain

###### General description

An individual can go from one state to another as time progresses. Time is modelled in fixed intervals. Individuals changes between states with a certain probability known as the transition probability. Transition probabilities could be constructed in a matrix known as probability transition matrix. When a Markov chain is irreducible his long-term behaviour is independent of the initial probabilities and known to be in a steady state. The states have an equilibrium distribution once the steady state is reached. (Savage, L. 2003)

###### Project Environment

Markov chains have been used in different environments such as production. (Winston, L) Control problems in production environment could be solved with Dynamic Programming approach. Dynamic Programming leads to a system of equations that is dynamic and corresponding to Markov states. (YIN, G. 2005. 271)

### Correct application

The initial state probabilities of the probability matrix must sum to one. Excel has a tool for Markov chains called "MARKOV.xls" The dynamics of the situation can be seen by clicking on the Graph tab. To determine the equilibrium distribution use Excel Solver. (Savage, L. 2003) When you have a chain that is not ergodic the theorem to reach steady state fails to hold. (Isaacson. 1676, Chapter 3)

## Forecasting

### General description

Forecasting is a method where statements are made of outcomes that have not yet happened.

### Project Environment

Probabilistic Forecasting Method is a method to forecast weather patterns with an output of probabilities.

### Correct application

Crystal Ball, an Excel add-in contains a forecasting module. The output variables that are called forecast cells are from interest. The forecast dialogue can also be defined by using the forecast dialog function.

## Capability study of Model output

### General description

Measure the difference between the actual lead time and lead time as it was with the MRP. (Swamidass, M. 2000. 421)

### Project Environment

Capability must be measured to determine how good the model output is performing. When the capability is not high enough, according to policy, measures must be taken to increase the capability.

### Correct application

The application of the capability study is a very broad field. Capability of almost any situation or system can be determined as long as they have some kind of measures that can show the desired level and the actual level of performance.

Crystal Ball Contains a module in Excel that that performs a distribution capability fitting. (Evans, R. 2010)

## Decision Analysis

### General description

Decision Analysis is a method for structuring and understanding decisions regarding problems of uncertainty. (Cendal, J. 2010, July)

### Project Environment

Decision analysis is used for uncertainties regarding probabilities. (Cendal, J. 2010, July)

### Correct application

Decision trees are an analytic model that can be used to conduct decision analysis. (Cendal, J. 2010, July)

## MATLAB

### General description

MATLAB is a software programme with great capabilities. MATLAB is the language of technical computing. MATLAB is a fourth-generation programming tool. (Hiebeler, D. 2010)

### Project Environment

MATLAB consist of many functions both mathematical and scientific. MATLAB has an interactive environment of algorithm development. "SOLVE" is a common function that enables the user to submit an equation that is solved for the variables unknown in the equation.

### Correct application

The language to programme in MATLAB is very sensitive and strict, and must be closely studies for correct execution. (Hiebeler, D. 2010)

## Static Testing

### General description

Static testing is a type of verification where testing is done without running the model. (Omicron.2003)

### Project Environment

It checks the common sense of the algorithm and the sanity of the model code. (Omicron.2003)

### Correct application

The application of this type of testing can be used by the designers who code the model, in isolation. The testing can be conducted by code reviews, inspections and by walkthroughs of the model. (Qastation. 2007-2010. Inove by Newease)

## Dynamic Testing

### General description

Dynamic testing is a type of validation where testing describe the dynamic behaviour of the running the model. Dynamic testing refers to the assessment of the software reaction from the model to variables that are not stable and vary over time

### Project Environment

It checks the common sense of the algorithm and the sanity of the model code. Once dynamic testing is completed, the software of the Model will be able to satisfy the user and the intended needs of the model.

### Correct application

The application of dynamic testing of software must in fact be executed by running the model. Dynamic Testing involves operating of the software, submitting input values and examination of the output values. This could be done through a few methods like Unit Testing, Incorporation Testing, System Testing and Approval Testing. (Omicron.2003)

## 7.3.2 Product Data Management

Product Data Management is the application of software that tracks and controls data of particular components of a product. Data tracked can involve:

- Technical specifications
- Development Specifications
- Manufacture specifications
- Material required
- Costs

(Arbe, K. 2001)

The information of the components is then stored and managed by the PDM system that serves as a central knowledge repository for process and production history. The PDM system can later release status updates of the separate components. Several information inputs and outputs can be stored and managed.

### Inputs

- CAD models
- Drawings
- Part number
- Part description
- Suppliers
- Vendors
- Measure unit
- Costs
- Material data sheets

(Arbe, K. 2001)

### Outputs

- Execution of Engineering change Management
- Control release on issues of components
- Build and Manipulate the BOM
- Assists in configuration management

(Arbe, K. 2001)

### Capabilities

- Access Control
- Component Classification
- Product Structure
- Engineering Changes
- Process Management
- Collaboration
- Storage and retrieval of product information
- Product Structure modelling and management
- Product tracking
- Resource Planning

(Arbe, K. 2001)

### Software

- C++
- C
- Java

(Arbe, K. 2001)

## 7.3.3 Material Requirements Planning

Creates schedules of components in production that identify the material requirements, quantities needed, and the dates of the orders to be released and received. “Getting the right materials to the right place at the right time.” (Chase, B. 2006) The MRP requires information inputs from the inventory department, the master schedule planning and the BOM. The BOM identifies the materials and quantities needed for each item.

### Input requirements

- BOM
- When required
- Inventory levels
- End item
- Planning data

### Outputs from MRP

- Production schedule
- Purchase schedule

MRP needs accurate input data. If the BOM undergo any changes during the production, the schedule output may change. Action already performed in production can't be changed as the schedule changes. (Hopp, 2004)

### 7.3.4 Bill of Materials

The bill of materials both identifies and lists the components of a finished product.

(Jon Clancy)

The BOM can also list the sequence in which you must create the product.

(Hopp, 2004)

**The BOM include:**

- Structure level
- Part number
- Revision level
- Quantity required
- Unit of measure
- Description
- Job indicator

(CIRAS)

The BOM must be accurate as a prerequisite to other operating systems. The BOM is the central source of information to perform product costing, inventory control and engineering.

## PART B

### 8. PROJECT APPROACH

The project approach aims to define the process to deepen understanding of the problems and subsequent solutions. It is a brief description and logical map of the following 5 sections to come, forming PART B of the project report.

#### Analysis

Conduct a complete analysis to be able to identify problem areas in more depth. This includes interviews, process studies, documentation research and historical lookups.

#### Problem Formulation

Use the data analysis to identify problems and conceptual problem areas.

#### Solution Concept

Define the concept around the problem areas and general approach to solving the problem areas.

#### Development of solution

Design the model with its different stages and functions. Show the interaction of the model stages with each other and the software systems.

#### Testing

Do the validation and verification of the model that is being developed.

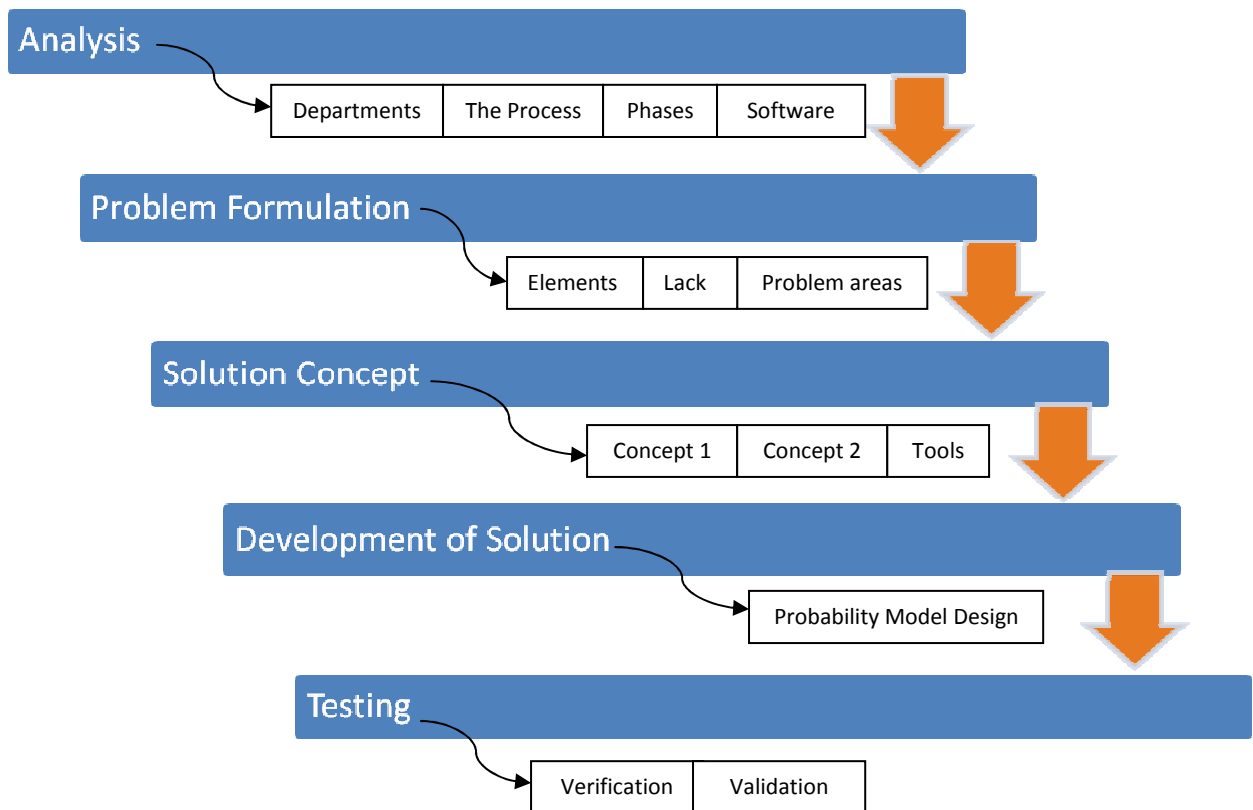


Figure 2: Project approach logical map



## 9. ANALYSIS

The analysis was conducted to get a better understanding of relevant project areas and the overall project environment. Once a complete Analysis was put together it was possible to start the Problem Formulation with a concrete background.

### 9.1 Relevant departments and stakeholders involved

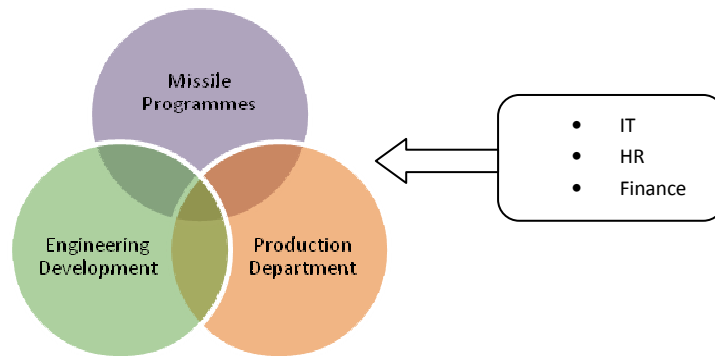


Figure 3: Relevant Departments

Denel Dynamics has 3 departments directly involved in the Process Life Cycle phases and stages. Throughout the entire report the colour coding for everything regarding Engineering Development would be represented in Green. Everything regarding Production will be displayed in orange and the Programme Managements will be displayed in purple.

The data regarding the problem were gathered by interviews, process studies, data reviews, historical research and documentation reviews.

#### Stakeholders in Missile Programmes

- System Engineers
- Configuration Management
- Support Facilities
- Specialized Consultants

The Missile Programmes are different divisions working on separate missile products. Therefore the Missile Programmes are directly involved in the entire life cycle of the specific missile product.

#### Stakeholders in Engineering Development and Production

The Engineering Development Department and Production Department mainly consists of Specialists, and Engineers. Engineers include Process Engineers, Electrical Engineers, Mechanical Engineers and Industrial Engineers. The Engineering Development Department and Production Department is only involved in some of the stages during the missile life cycle. More around this is discussed in the next sections, section 9.2 and 9.3.

*See Appendix Figure A1 for: Organization Departments Structure*

## 9.2 The Life Cycle Process

The whole process, on its highest level prospect, mainly consists of four important stages and five important phases. All the documentation, processes, life cycles, departments and planning is done around them.

**The four stages form the base of the Missile life cycle time and they are:**

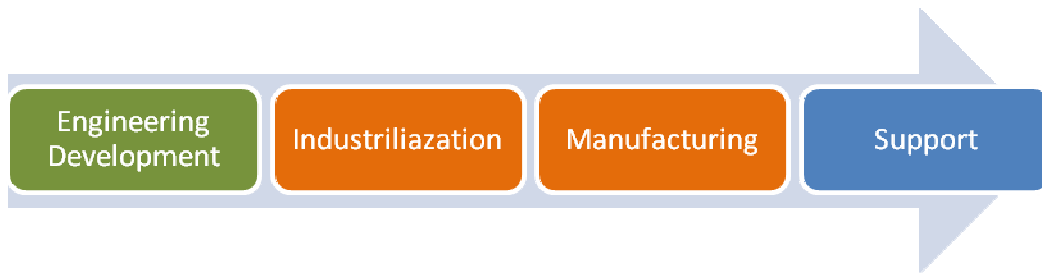


Figure 4: The life cycle process (high level) divided into 4 stages

The Engineering Development Stage 1, from figure 2, consists of 3 phases represented in green and showed in figure 5. Both the Industrialization and Manufacturing stages make up the Production phase showed in orange. Stage four, also Phase four represented in blue, is to support the client while operating the complex product.

**The Process consists of 5 main Phases:**

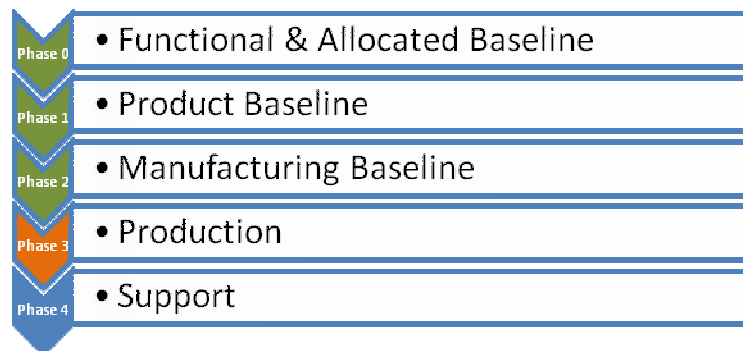


Figure 5: The Life Cycle Process (high level) divided into 5 Phases

### Typical life cycle process times

- Engineering Development life cycle: 3-5 years
- Production life cycle: 1-3 years
- Support to client: 10-15 years

Documentation of this report is based around the structure of this Process life cycle. The model designed and discussed later in section 12 will aim to manage the maturity of the BOM over the entire Process life cycle as it is showed above in figure 4 and 5.

### *9.3 Software systems that support the different phases and stages*

- **PDM LINK – Play a key role in Phases 1 – 3 or Stage 1**
  - Engineering Development control
  - Monitor system progress
  - Document material attributes
  - Document component attributes
  - Store all design data
  
- **SAP – Involved over entire life cycle process, but play the key role in phase 4 & 5 or Stages 2 - 4**
  - ERP system of Denel Dynamics
  - Does the complete MRP and MPS (Master Production Schedule)
  - Manually able to adjust and manage resource utilization

### *9.4 Further explanation of the Stages in the life cycle Process*

#### **9.4.1 Engineering Development Stage 1**

##### **Design Considerations**

- Specifications
- Production
- Compliance
- Cost
- Safety
- Obsolescence

##### **Measures of performance**

- Costs
- Quality
- Timing
- Technical conformance

##### **Stake holders**

- Design Engineers
- Subcontractors
- Production Engineers
- Support Engineers

During the Engineering Development Phases a few key process steps take place to assure the quality and completeness of products are of a high standard. The steps are shown in figure 6 below in a V-diagram starting at the customer need and ending at the BOM with the Production Readiness Report.

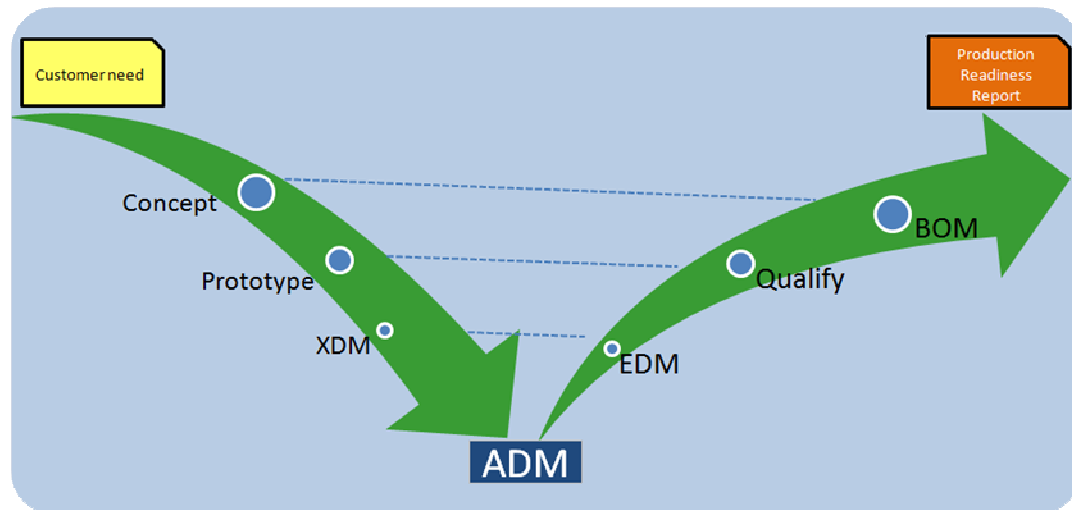


Figure 6: Engineering Development Process steps

### Explanation of the steps in figure 6

#### *Concept:*

This is the phase during which the Engineers describe the basic concept of the design towards achieving the desired BOM at the end of the engineering development process.

#### *Prototype:*

This is the phase during which the first model is build. The model is used to test the concept design and evaluate the design according to specifications. Once tests verify the concept can work, the next stage is approached.

#### *XDM:*

**Experimental Development Model** phase during which Engineers do the detail design, of the selected design, from the prototype phase. This model is developed with the desired EDM model specifications in mind.

#### *ADM:*

**Advanced Development Model** phase is where the Engineers improve on XDM after a test series is done. Test series consist of many very important tests to make sure the design is of a satisfactory standard and quality to form part of the high performing missile end product. This model forms the key basis of the Engineering Development Life Cycle.

#### *EDM:*

**Engineering Development Model** where the Engineers do last round improvements supported by the original detail design of the XDM.

*Qualify:*

The process where the Engineers build and test a few EDM's under various extreme environmental conditions to qualify the final design. The aim of Qualification is to make sure once production starts that it has been Qualified according to all specifications. The better a component is Qualified, the less chances are of changes surfacing during production.

*BOM:*

Bill of Materials that is ready for production according to the original customer need. Has a Product Data Index, PDI, which describes the BOM with all the necessary data of the component or assembly.

### 9.4.2 Industrialization Stage 2

The main purpose of Industrialization is to prepare the specific component with regards to production requirements. The process requires testing and verifying all the components with their specifications in the production environment. Many new production concerns surface during this stage of the process. Therefore it is very important to conduct industrialization thoroughly and sort out all problems before switching to mass production. Once mass production starts the financial impact and delay consequences of newly surfacing problems are very high.

*See Appendix Figure A6 for: Industrialization Process*

### 9.4.3 Manufacturing Stage 3

It is best to only start manufacturing once the Industrialization is completed. The Production Department uses SAP to do the planning of production. SAP generates a MRP from where the MPS, (Master Production Schedule) can be done. The Production Department is responsible for procurement, manufacturing and assembly. The Production Department must also assist the Engineers during development phases steps, discussed in section 9.4.1, of the different models that is used for testing and evaluations to qualify the BOM.

*See Appendix Figure A4 for: Production Process*

### 9.4.4 Support Stage 4

Support plays an important role during the Process life cycle. During the earlier stages of the Process life cycle, provision and planning must be made to assure support would be possible to execute far into the future of the product and part lifetimes. That means parts must still

be able to be upgraded by design, to keep up with developing technologies, and manufactured according to customer needs.

### 9.5 Part Design Changes occurring during all the stages

It is very important to manage all the changes of parts during the Process life cycle. If this is not done properly, changes may influence other areas of the process without even knowing the negative consequences. Therefore a complete process is set out to make sure changes of any kind are done according to standardized specifications. The PDM Link system is used to manage the change cycle through the different steps and with the correct involvement of all parties. The change cycle is the responsibility of the Configuration Management division. They must assure the filing of historical change data and managing current changes accordingly through the standard change cycle showed in the appendix figure A2.

**The standard change cycle and the data entering the cycle from different system locations:**

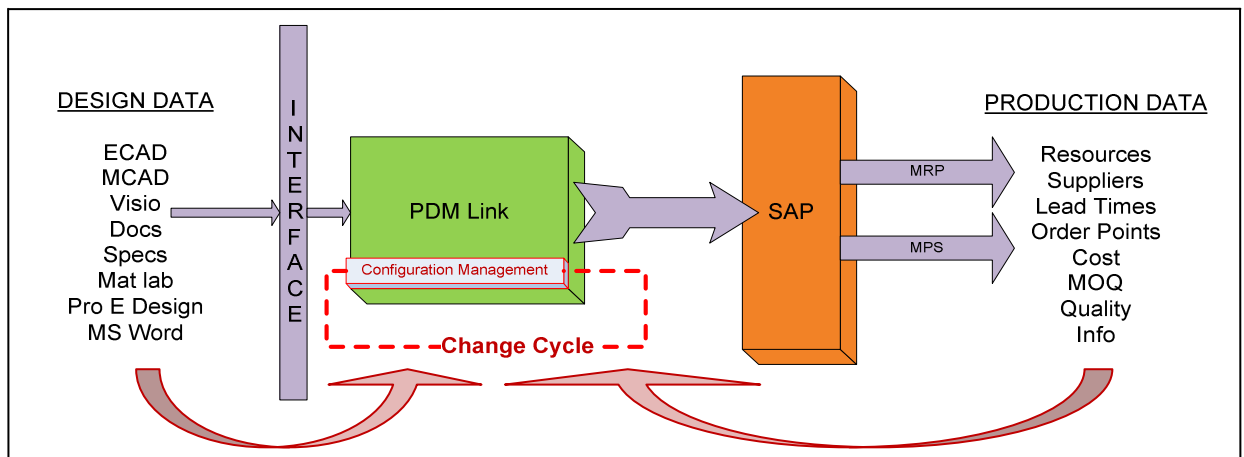


Figure 7: Change cycle position and structure

In the above figure it is illustrated how the change cycle, showed in red, is managed by Configuration management which takes place in the PDM Link software system, showed in green. The PDM Link and SAP systems separately contain all the Design and Production Data, displayed on the left and right of the figure, which enters the change cycle whenever a change in the part data may occur. Part changes may occur at any point of the Process life cycle and when they do the part data are simply send back to PDM Link to go through the change cycle regardless of how production planning is influenced.

The change cycle is relevant and further discussed in this report since the part changes are the main origin of the problems in the MRP and MPS. It forms part of one of the main problem areas later identified and solved in section 10 and 11.

*See Appendix Figure A2 for: Change Cycle Process and system interaction*

## 9.6 PDM Link and SAP software systems documentation

PDM Link and SAP has different documentation structures and names. These names must be synchronized in order to be able to create an interface between the two systems. Because SAP is mostly part of Production and PDM Link part of Engineering Development, the interface is needed to improve the communication and integration between the departments. With the improved integration between departments, the Process life cycle could be executed faster with fewer communication errors and part changes, discussed in section 8.5.

*See Appendix Figure A3 for: Document Structure Flow*

Document Synchronization Between SAP and PDM Link Software Systems		
PDM Link	SAP	
Name in PDM Link	Name in SAP	Compiled of:
PR	FRACAS	Every Document of Components
Wt DOC	DIR	
Wt PART	MM	Raw Materials of Component
PR	ECP	Changes
ECN		
ECR		
PS	BOM	All MM's to specific assembly
<i>Reports</i>		
	PDI	All DIR's to specific assembly
	DDI	All Documents to specific assembly

*Table 1: Software documentation*

The documentation structure is important since the newly designed model, discussed in section 12, have to feed from different documentation out of both the software systems. The model will have an interface with SAP in the production environment and an interface with PDM Link in the engineering development environment and generate model outputs accordingly. The table shows what the different documentation from the different software systems are compiled of. PDM Link documentation is showed in green and SAP documentation is showed in orange. Part changes discussed in section 8.5 are documented by the PR, ECN, ECR and ECP documents.

The Maturity of each component will play a role to break the model down into the finest form of management. The finest part in the product structure is a single component, displayed in the Appendix in figure A3. Most of the attributes for the new model could be acquired from the PDI, (Product Data Index), since all the MM's, (Master Material), are included there.

See Appendix Figure A7 for: Document Structure

## 10. PROBLEM FORMULATION

### 10.1 Elements and their trade-offs

Denel Dynamics function in a very competitive world today. The Defence market requires a very high standard of quality and performance. The contracts and development phases is very long and involves large amounts of money. Processes are planned very exact to make sure the execution is effective.

In achieving this goal of being effective, there are 3 elements that must be taken into account throughout the product life cycle.

#### The 3 Elements

Most businesses concentrate on these 3 elements, but in the environment of Denel Dynamics these 3 elements are especially important. The whole process and problem formulation of the organization's aim evolve around these 3 main concerns. Also all the current decisions in the workplace and the decisions regarding the structuring in the future resolve around the elements. Therefore all the problems identified and further discussed in the following sections, is because they either affect the quality, time or cost of the process.

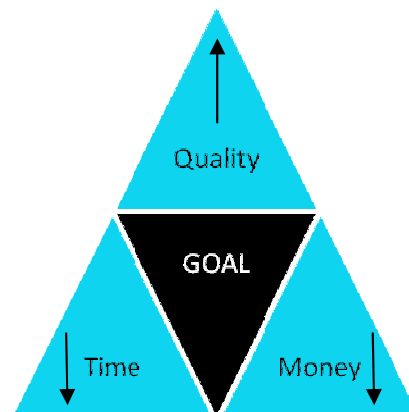


Figure 8: Balancing the key elements

**The challenge is to reach a high level of quality within time and cost effective**

#### The influence that Change Management has on the trade-offs

To reach the goal, the change management process must be effectively executed. The change management cycle, discussed in section 8.5, plays a crucial role in managing these changes that could later result in problems occurring in the process.



If all changes are managed within the right time and only at acceptable time frames of the process, costs and time could easily be reduced. On the other hand, the more changes are made to the parts, the higher the quality of parts and the overall product becomes. This results in a problematic trade-off between the 3 elements.

During the interviews with all the departments it became evident that Engineering is always pushing for changes to improve the design, whilst Manufacturing need a mature BOM to ensure effective material requirements planning. Managing the trade-off's between higher quality vs. time and money leads to the conflict between Engineering Development and the Production Department. The conflict between the two departments can be assigned to a lack of department integration, discussed in the next section, section 10.2.

## *10.2 Describing the Lack of Department Integration*

The Engineering Development Department and the Production Department wants to execute their role in the life cycle as effective as possible. This is obviously extremely difficult to achieve in such a specialized field of work and performance. If the Departments function separate from each other, their interface would be easy. Working together as an integrated group on one product is a different scenario to achieve effectiveness. Both specialize in their own field of work that is completely different from the other one. This result in a lack of communication between departments and departments not understanding the different department environments.

### ➤ Perspective of the Engineering Development Department in their own environment

- The production department does not know anything about complex engineering designs
- The Production Department must be able to have all material ready for use at any given time during the engineering development phases.
- If time is running out it is because the Production Department did not start early enough

### ➤ Perspective of the Production Department in their own environment

- The Engineering Department thinks that changes is part of the process, everyone must embrace them whenever they occur.
- The Engineering Department does not consider possible production concerns in the designing phases
- The Engineering Department is so concerned with achieving the highest level of quality; they completely ignore time and money constraints

### 10.3 Problem identification



#### General problems

- Configuration Management wastes time managing all the changes
- Production teams are not involved enough in the earlier stages of the design life cycles
- Programme Managers must determine volumes of production before industrialization phase, because you cannot easily change volume quantities after the BOM qualification.
- Everyone has to wait for the slowest part in the process
- Engineering Development cannot always follow a standardized processes
- Development does not evaluate and test enough with regards to production requirements
- MPS planning executed too early or too late causes waste
- Engineers are only concerned with having the best design, regardless of the consequences of changes in the designs and specifications of them.
- Planning of MPS done over and over to keep up with the changes causes instability

#### List of effects due to general problems

- Slip of milestones
- Scrap in Data Packs
- Continuously changing designs and the environment
- Wrong acquisitions
- Wrong material
- Designs expires if not managed
- Procurement delays
- Parts become unobtainable
- Turn over time is high
- Resources are wasted
- Transfers of the BOM is not managed well

#### Summary of main problem areas caused by the effects

-  No stable Production Plan
-  No knowledge of when to transfer the BOM if time is pressing

Due to the main problems and effects listed above, the original goal of effectiveness is not reached. **Money** is lost with insufficient planning, that wastes a lot of **time** to

re-plan and decrease the **quality** of delivery due to chaos in production. The two main problems must be addressed. The main problems are occurring in two main areas, further explained in the following section, section 10.4.

### 10.4 Further explanation of main problems and their occurrence in the process

This figure illustrates the involvement of the different departments during the entire process life cycle. All the green represents the Engineering Development side and their software system PDM Link. All the orange and red represents the Production Department side and their software system SAP. The red also represents the critical overlap between the two departments. The processes from each department meet where the BOM is transferred to Production. This is under normal conditions an easy interface that is triggered the moment a part is qualified after development. But under time pressing conditions it is hard to determine the point in time to transfer the BOM between departments in an effective manner.

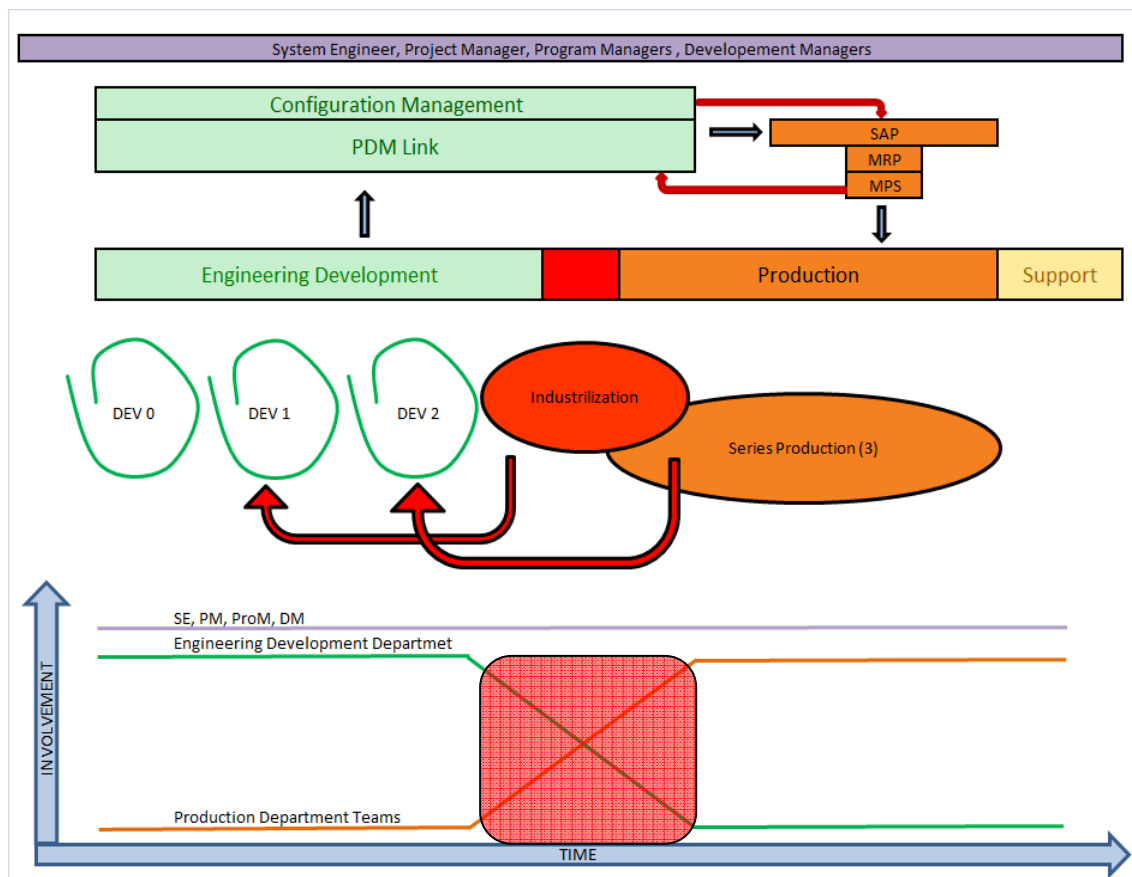


Figure 9: Main Problem occurrences

Once parts are transferred the Production Department can start with the production planning and execution. Without any engineering changes the interface operates smoothly. But this interface is hampered if BOM changes are required after the transfer has been made. The parts have to again go through development cycles and be re-qualified to only then re-enter the Material Requirements Planning. The tedious process is indicated by the

red arrows in figure 9. Such change requests leads to loss in schedule and require funds to re-qualify the parts.

During the transfer, the involvement of the Engineering Development Department decline and the involvement of the Production Engineers escalate. Their involvement can be seen on the bottom of figure 9 with regards to time. The point in time where the amount of the involvement of the departments crosses is referred to as the transfer point.

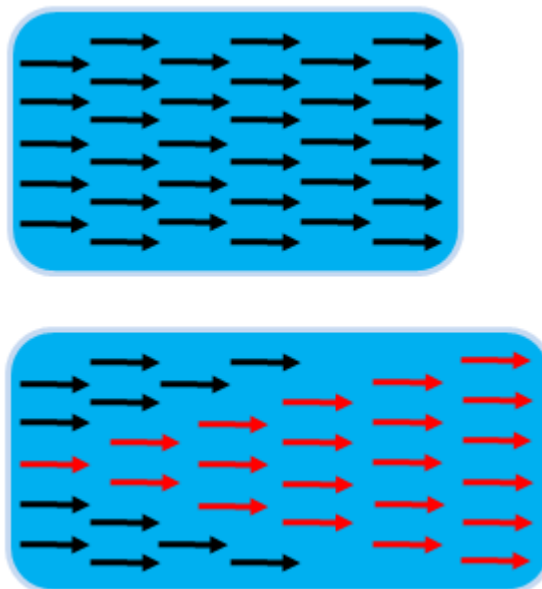
### **Explaining the effect of no stable transfer timing of the BOM, when time is pressing**

If the BOM is transferred to early, the BOM is still immature and will probably undergo more changes. The result is the BOM wastes more time by going all the way back to get changes done, than original time saved by sending the BOM earlier.

If the BOM is held back to long and transferred later in time, chances are good all the changes on the BOM is sorted out, but the BOM will most probably be too late to effectively utilize time in planning of the Production schedule.

### **Explaining the effect of unstable Production Plan**

If any part of the production planning slips for any reason the consequences turn out to be far bigger than originally thought it would be. Basically if there is any change in the MRP the whole MPS must be re-planned immediately to prevent slip in all the parts of the main schedule.



*Figure 10: MPS Ripple effect*

The top block of figure 10 shows with an arrow representation how the planning originally looks in the MRP. The diagram just below shows the dramatic effect of only one part

slipping. If immediate action is not taken to redo the MRP after one part starts to slip, it influences the rest of the parts until virtually all the parts are behind schedule.

## 11. SOLUTION CONCEPT

### 11.1 How to optimize the transfer timing of the BOM

The ideal solution is to follow the complete system engineering process and qualify all parts before transferring the BOM.

If delivery schedules are pressing for transfer under risk it is proposed that an intelligent model be added to monitor maturity of the parts before they are transferred. In concept the model will ensure the risk level is satisfactory before transferring the part. The transfer point will be managed in accordance with pressures on time and money.

#### 11.1.1 Explaining a parallel vs. a serial process

A representation of the two most extreme scenarios of the execution of the transfer

		Money Availability	Time Availability
Scenario 1 (parallel)	Optimistic Process	Limited	Limited
Scenario 2 (serial)	Ideal Process	Unlimited	Unlimited

Table 2: Transfer; extreme scenarios

#### Scenario 1 (Parallel)

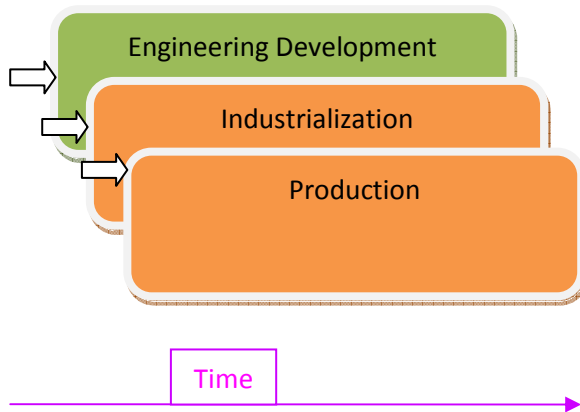


Figure11: Transfer Scenario 1

#### Scenario 2 (Serial)

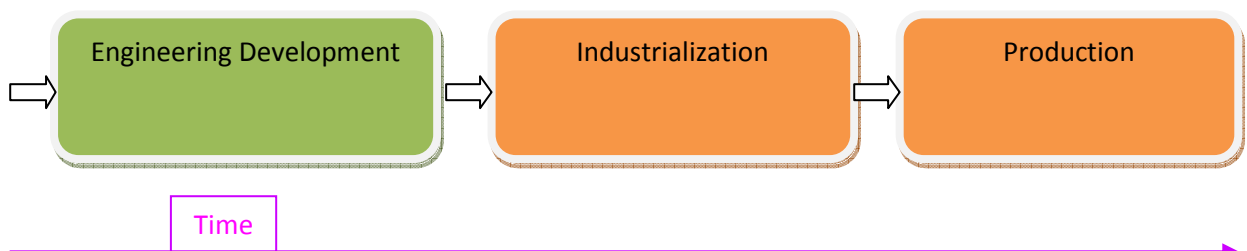


Figure12: Transfer Scenario 2

Regardless of which scenario is followed, changes in the design will always be present. The difference is the distribution of the changes. The distribution of the changes that affect the process is responsible for the way the process costs are made up.

Relationship of changes with cost and time

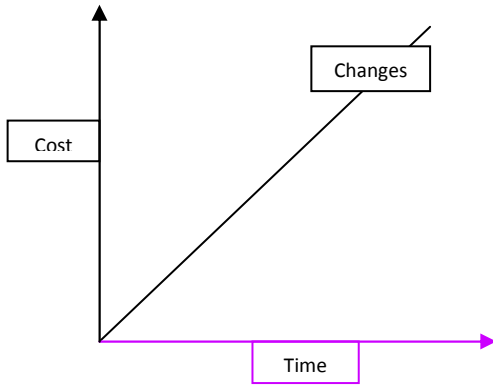


Figure 13: Relationship

**Scenario 1**

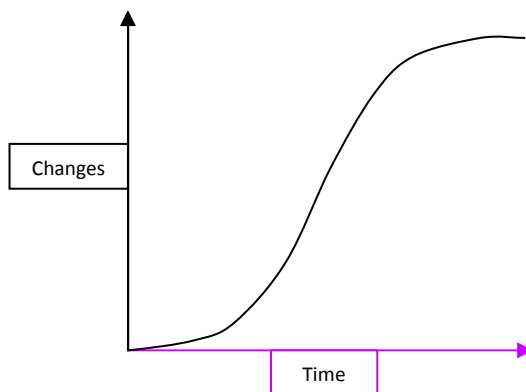


Figure 14: Scenario 1

**Scenario 2**

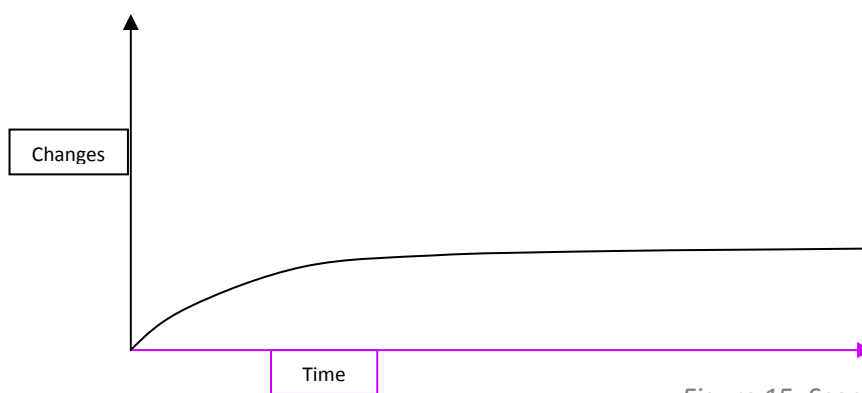


Figure 15: Scenario 2

Scenario 1 has a shorter curve regarding the time axis but the curve is very high in the amount of changes affecting the process from running smoothly. Therefore the area of the curve is fairly large. Scenario 2 on the other hand has a lot less changes throughout the life cycle but the changes is over so long period that the area of the curve is also very large.

It can be seen for both extreme scenarios the cost is very high. The reason why scenario 1's curve start out with a lower rate of changes occurring, is because they have the help of production teams from the start. Later the rate of changes occurring is suddenly very high because the production life cycle was started without any of the engineering models properly tested and qualified. Scenario 2's changes is sorted out early in the Engineering stage. Once production starts there are very little changes still affecting the process. This is because most of the engineered designs were properly tested and qualified during the Engineering stage early on.

It is clear from this analysis that a compromise between the parallel and series process scenarios must be found.

### 11.1.2 Explaining the Concept of the model

The model will take the maturity of parts into account and together with time and cost considerations determine the best point to transfer the BOM from Engineering to Industrialization and then in turn to Production.

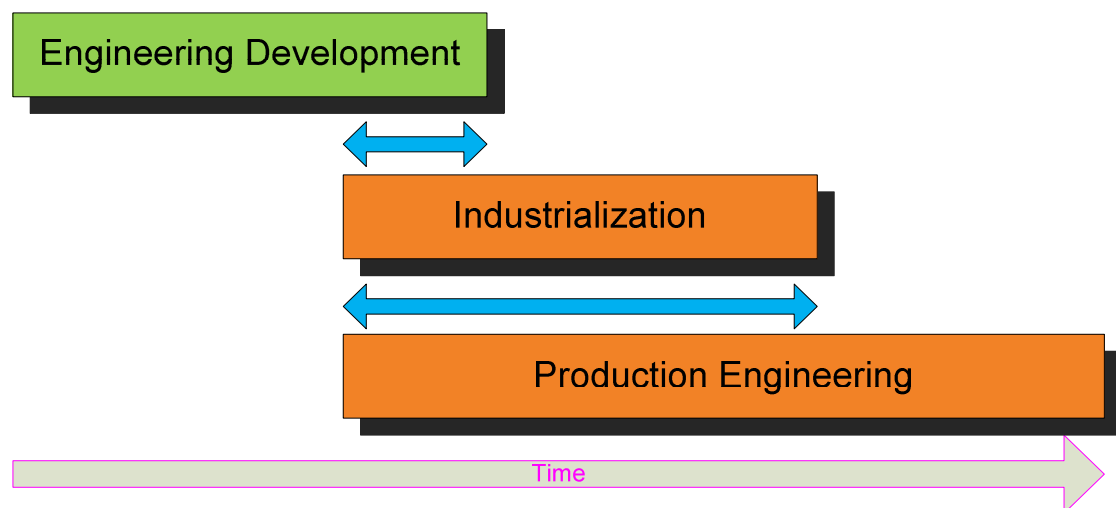


Figure 16: Showing overlapping durations between departments

The models will intent to determine the length of the overlapping durations between the departments represented in the blue arrows.

## 11.2 How to improve the stability of the Production Plan

### Feasibility Study

Investigation has been done to roughly estimate the amount of parts slipping in the production process. Parts can be divided into 3 types of groups with regards to slipping.

Group	Percentage of Parts	% Time Slip
A	20%	50% - 100%
B	50%	1% - 50%
C	30%	0%














Table 3: Production time slip results

From this statistics it is possible to estimate the average production slip of all parts to be 38%. An easy solution would be to adjust all MRP time scheduling with a factor of 1.38. This would improve the current situation but the ripple effect, explained in figure 10, will still escalate the problem. Parts that have a time slip of more than 38 %, although they are a small portion, will cause all the rest of the parts to slip more and more.

It is clear from this that provision must be added to the Production planning that is continuously managed according to maturity levels of the part. This will help to reduce the ripple effect explained in figures 10 and ensure more stable Production Planning for the future.

## 11.3 Tools and methods identified to solve the problem

Various tools and methods were investigated during the search and exploitation of the project problem. A few of them were identified as tools that could be effectively used in solving the problem on hand. Listed below are some of these tools and methods.

-  MATLAB software
-  Decision Analysis
-  Weighted Average Measuring
-  Markov chains steady state probability calculations
-  Probability Estimations
-  Excel Software
-  Capability Testing
-  Distributions plots of Probabilities
-  Mathematical functions
-  Populating the Matrix mathematically
-  Feasibility studies
-  Static Testing
-  Dynamic Testing



## 12. DEVELOPMENT OF SOLUTION

### 12.1 Integrating the Model into the process

The figure below shows the conceptual position of the Maturity Model. The model's cycles are represented by green and the model outputs are displayed in red. The main inputs are data from PDM Link and the parts re-entering the model for calculation after failing the capability test. The two main model outputs are the buffer added in the MRP and the management of the transfer point between PDM Link and SAP.

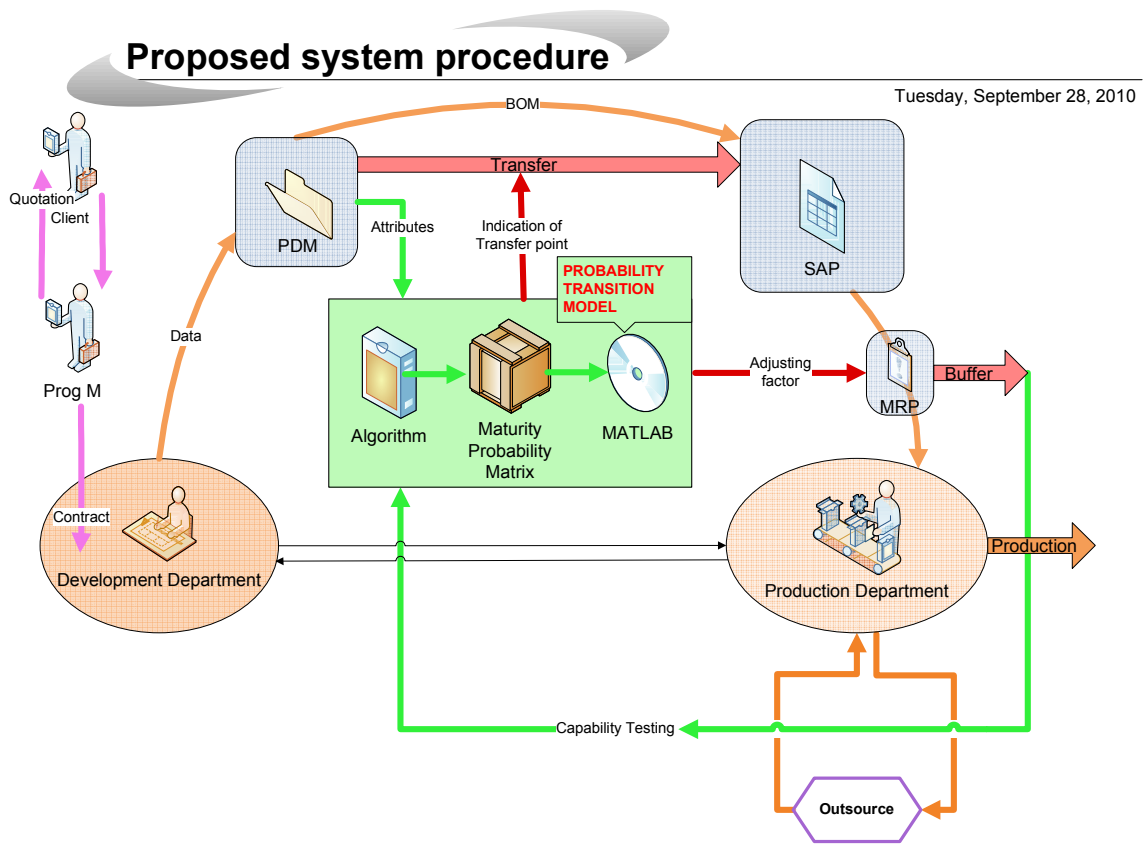


Figure 17

### 12.2 Brief description of the Model function

The maturity of each part will be monitored by the Maturity Model from the moment the part enters the PDM Link system. If the maturity of a part is satisfactory according to risk and other PDM link specifications, the model will permit the part to be transferred from PDM Link to SAP. On that same instance, the model determines the optimum part maturity level to use in determining the most accurate adjusting factor. The adjusting factor will then be used to add a buffer in the MRP. Finally the Maturity Model will check the accuracy of the estimated adjusting factor to determine the model capability as time goes on. When the part's

progress time fall outside the allowable range of times, the model will recalculate the adjusting factor to get a new estimation of the allowable time range.

### 12.3 Essence: Determining the Maturity level

By establishing the maturity level of each individual part it is possible to make assumptions in how to treat the part with regards to the transfer point between departments and the production planning. The Maturity level will indicate how much development has gone into the part in order to get the part in a stable state with regard to changes. The maturity levels can be expressed from zero to any amount, depending on how advance the model is designed.

For the purpose of simplicity the following examples and explanations only consists of 10 maturity levels. Level 1 is the most immature level and level 10 is the most mature level.

### 12.4 The Maturity Probability Model

The model will do several calculations and check conditions to effectively determine the maturity level of individual parts. The model will consist of 7 stages, each fulfilling a purpose in achieving the end result.

**The 7 main stages of the model are:**

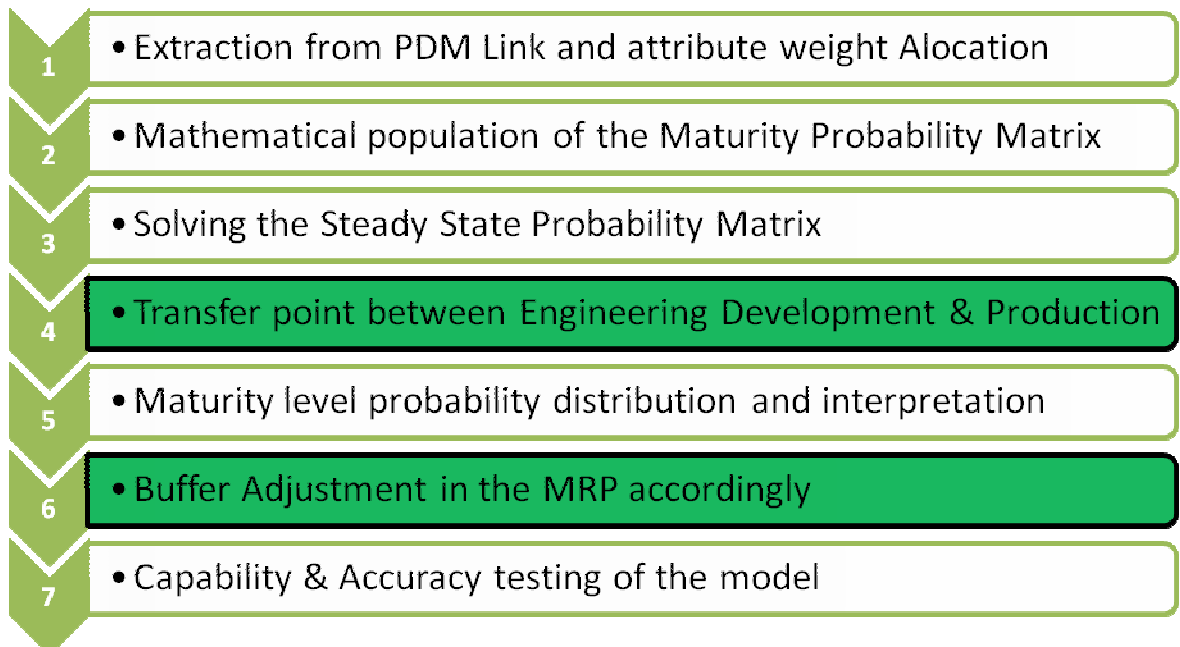


Figure 18: Stages of the model

Listed below are the main deliverables, interfaces, feed in data and capabilities of the Maturity Model.

**Model main Deliverables**

- Transfer Point between Departments (stage 4)

- Buffer Adjusting factor in the MRP (stage 6)

#### Model Interfaces

- PDM Link to Excel
- Excel to MATLAB
- MATLAB to Excel
- Excel to SAP

#### Feed in Data that forms part of the Model design and start up data

- Attribute weight allocation
- Algorithm factors
- Rate of algorithm factors changing
- % Risk to take to transfer a part
- Final adjusting factor start point
- Final adjusting factor increase rate
- Factor to determine the back loop point after capability study

#### Other Feed in Data that forms part of the Model attribute inputs and running data

- Time available for the part before starting production
- Priority of part before production
- Value of the part
- Time available for the part in production
- Priority of the part in production

#### Model Capabilities

- Consider any attributes from PDM-link
- Monitor part maturity continuously
- Test model outputs for accuracy

#### Color coding throughout the following examples in section 12.5

During all the stages of demonstrating and explaining the different phases,

User specification	Purple
Predefined Specifications	Navy
PDM Link Inputs	Green
Data flowing between stages	Yellow

the colors will represent the same type of action in the Model. The actions with their colors can be seen in the table

below.

Table 3: Color coding

Purple is very important because the user of the system must specify the purple inputs as part of the model execution.

## 12.5 Model stages 1 to 7, design and demonstrations



### 1 Extraction from PDM Link and attribute weight calculation

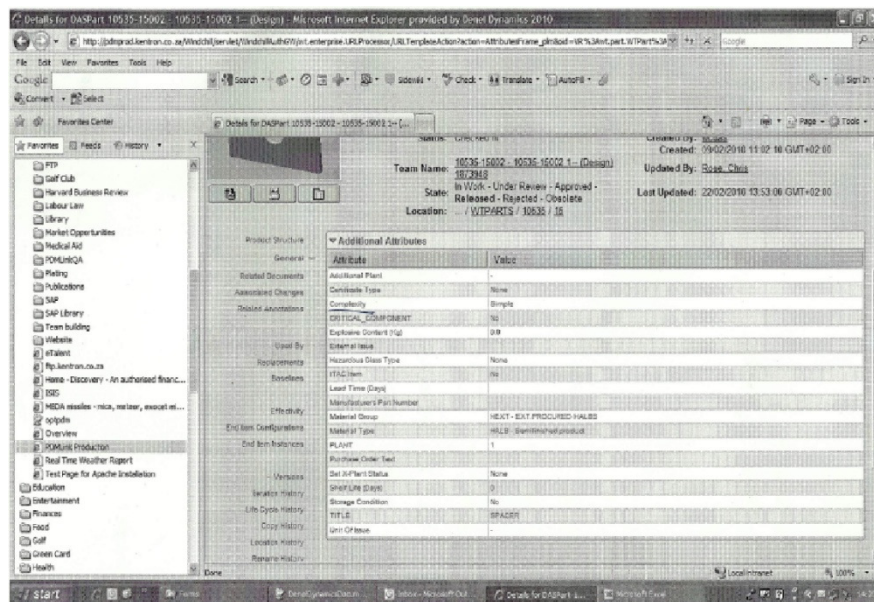


Figure 19: PDM Link Attributes as it is on the Computer system

### Attributes extracted from PDM Link

All the attributes are managed by PDM Link. An interface would make it possible to extract attribute information in the correct format for the model to make use of.

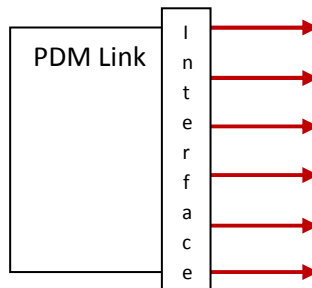


Figure 20: Attributes extraction from PDM Link

### Applicable Attributes from PDM Link

- Complexity

- Manufacture
  - Production
  - Design
  - Assembly
- Critical Component state
- Lead time
- Material Group
  
- Shelf live
  - Last Production
  - Last Design update
- Failures
  - Previous Phase
  - Previous Development
  - Previous Production
- Associated Changes
  - Recently
  - While back
  - Long ago
  - Reviews
- Versions (previous acts)
- Related annotations
- Used by
- Replacements
- Effectively
- Used by (Dependability)
- Iteration History
- Life Cycle History
- Location History

All these attributes form part of the algorithm to mathematically determine the probability maturity matrix, explained in stage 2. For simplicity only 4 attributes is used in the simplified example following below.

The attributes all have a scale that gives a numerical measure of the attribute. Because attributes play a different role in the maturity for different parts, the user can specify the different weight percentages of the attributes for different parts, as in figure 21.

Attributes are divided into two types, positive and negative affecting attributes. A simple conversion calculation converts the two types of attributes to the same type of measure in the scale column. The product of the scale value and the allocated weight gives a result that can be anything from zero to ten. All the results are added together to give another result that also have a measure between zero and ten. The result can only add up to ten because

of the restriction set by the allocated weight percentages. Once the result is calculated it is divided by 10 to give the final output namely the Result Total.

SIMPLIFIED EXAMPLE no. 1

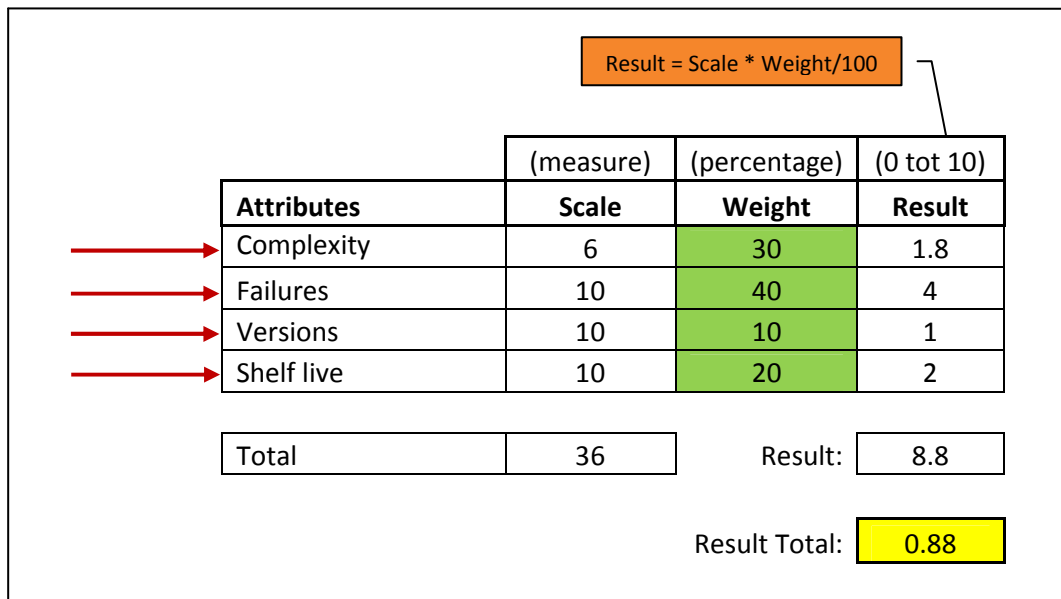


Figure 21: Example of how stage1 calculates the result total of all the attributes

The inputs, for figure 21, indicated by the red arrows can be related back to figure 20 where the red arrows represent the attributes as they are extracted from PDM Link.

The purpose of this stage is to determine the Result Total of 0.88 displayed in yellow. That will be the input of the next stage, stage 2. The Result Total value can lie between zero and one, as shown in figure 22. A critical point on the Result Total scale is at 0.5. That is the break point that distinguishes the calculations to be of one or another kind. Most of the time it is either positive or negative calculations depending on the Result Total being either above or below the 0.5 point.

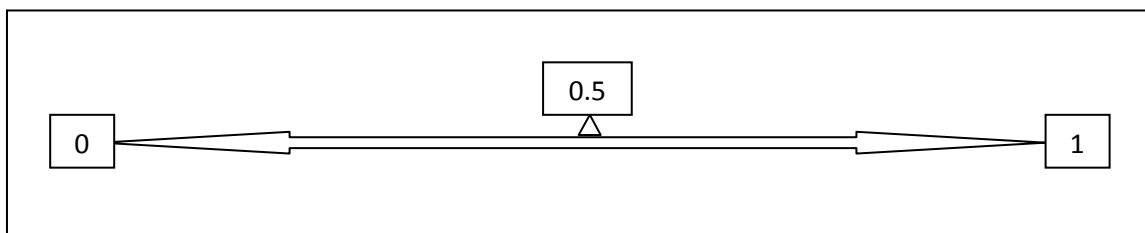
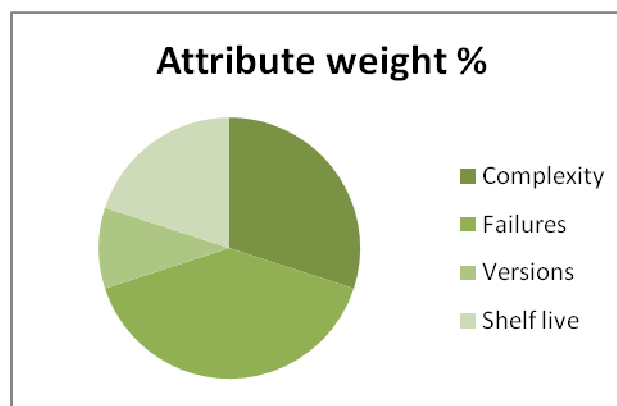


Figure 22: Result Total Scale

From the simplified example no.1 it can be seen that scale measures are typically from 0 to 10. “Versions” for instance is a positive attribute because the more versions there have been made, the more mature they become. So “versions” with a value of zero, is first converted to a 10 in order to have the same scale of measures as the negative attribute.

Failures for instance are assigned the highest weight percentage of 40%. The user can choose different weight percentages as the user requirements are further exploited in the future and as the model is been developed to a more advance level.



Graph 1: Weight percentages assigned to attributes extracted from PDM Link



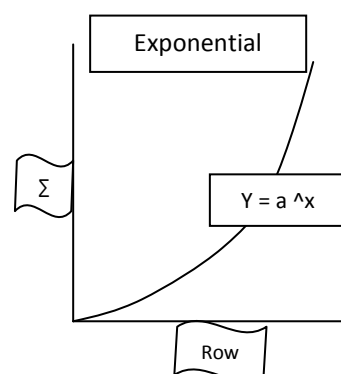
## Mathematical population of the Maturity Probability Matrix

### The General Curves forming the Maturity Probability Matrix population pattern

A few general curves form the platform to populate the Maturity Probability Matrix. Each general curve has a start point, a curve type and a rate of change. The general curves can be manipulated for different future scenarios in order to represent certain part attributes. The main inputs in determining each curve's characteristics are the Result Total calculated in stage one. The concept of populating the Maturity Probability Matrix is based on the most extreme upper and most extreme lower scenario and modelling all the combinations in between.

### Curve Types that could be used to populate the Maturity Probability Matrix

Many curve types can be used to represent the probability distribution of a certain part in the maturity levels. Using past data as a starting point, it was decided to settle with the exponential function as can be seen in graph 2. In the future this function can be changed to other and more advance functions as new problems get analysed and user requirements change.



Graph 2: Curves based on the Exponential Function

### Rate of Change of the curves by which the Probability Maturity Matrix are populated

By choosing different values for  $a$ , the rate of change of the maturity probability distribution gets increased or decreased. The main source that lets the value of " $a$ " vary is the Result Total obtained from stage 1. Thus the closer the Result Total value is to 0 or 1, the larger the " $a$ " value becomes. The closer the Result Total value is to 0.5, the smaller the " $a$ " value



becomes. The curves represents the change rate of probability over the rows that increases as the Result Total values moves further away from 0.5.

Referring back to figure 22 a Result Total of 0.5 plays a key role in the value of "a". Therefore the two graphs below, in figure 23, shows the curve slopes together at 0 and 1, and then at 0.5.

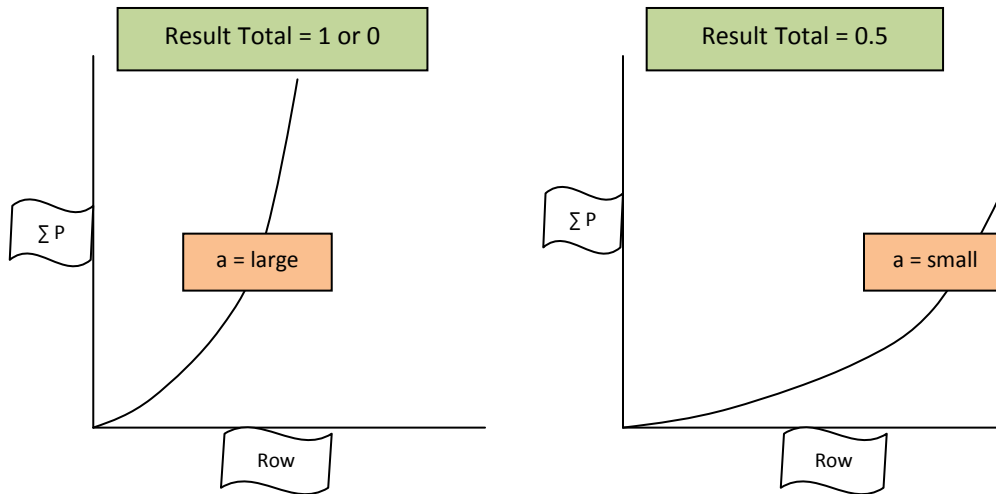


Figure 23: Different rates of change for different "a" values

**Different areas to consider in the Matrix, when defining the oblique curves**

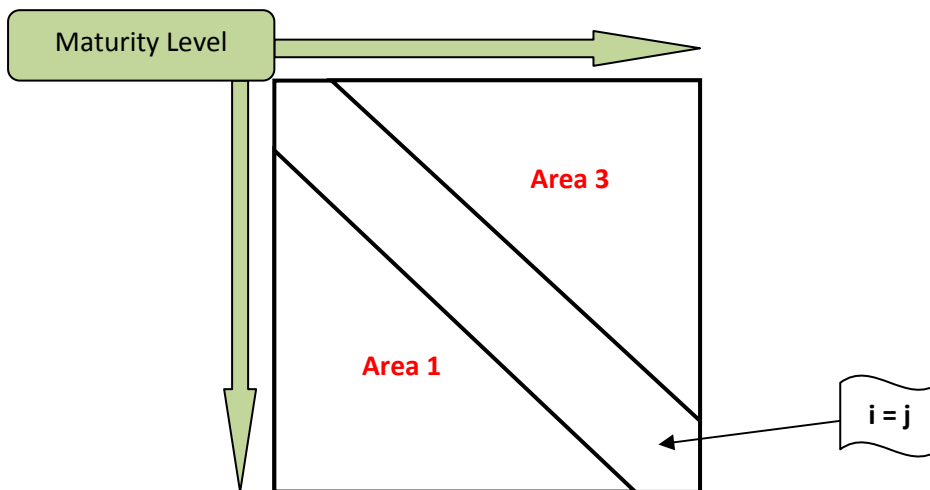


Figure 24: Different areas in the Matrix when defining Oblique curves

### Oblique Lines in the Matrix and their relationships with each other

The oblique lines have different curves representing them, depending on the characteristics of the part. The Result Total makes a distinct difference for values below and above 0.5. The 3 main areas are the right top triangle of the matrix, the left bottom triangle of the matrix and the middle oblique line right through the matrix as can be seen in figure 24. In area 2 shown above, the  $i = j$  which means that it is only one set of values down the middle line. Areas 1 and 3 have more than one set of oblique lines occurring in them.

Below are the graphs by which the oblique lines are formed. The graphs have different shapes at different areas in the matrix. The areas are shown in the red arrows located down the middle of the figure below. The graphs also have different shapes for a different Result Total inputs, shown in the top red blocks. The relationships between the curves are visible by looking at the unknowns "M" and "N" that represents the starting and ending points of the graphs. They are highlighted in green and yellow to make it easier to distinguish them.

Result Total < 0.5

Result Total > 0.5

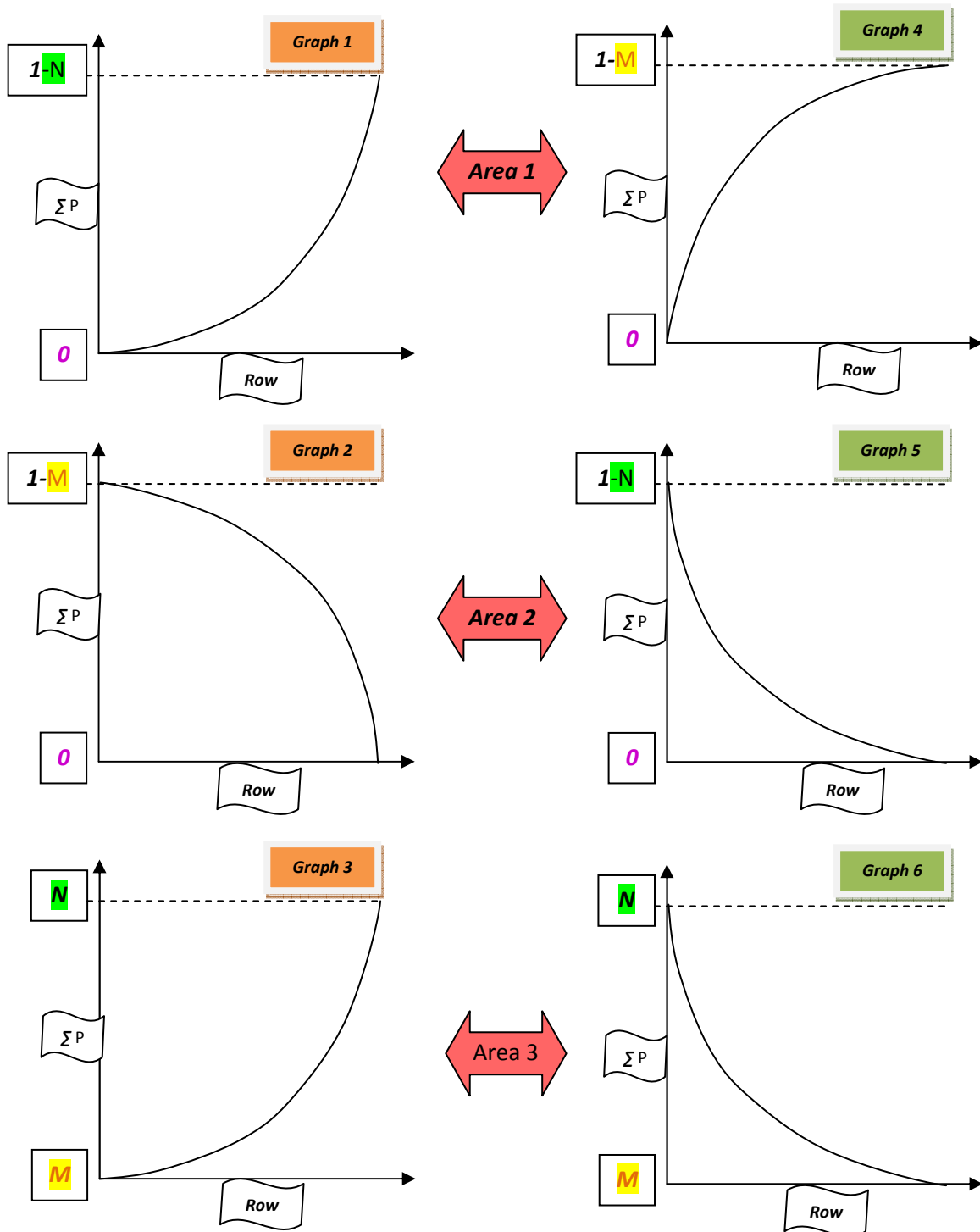


Figure 25: Graph shapes for different areas and Result Totals

**Relationships between the different graphs in the above figure 26**

- $N + M = 1$
- Graph 1 and 5 both have a start and end point of either 0 or 1-N.
- Graph 2 and 4 both have a start and end point of either 0 or 1-M.
- Graph 3 and 6 both have a start and end point of either M or N.

### Directions of the curves that populate the Maturity Probability Matrix

Figure 27 below shows the 5 main curves and their directions in the Maturity Probability Matrix. The arrows and blocks represent all the curves on the matrix in that direction and not only the single curve that the arrow lies on.

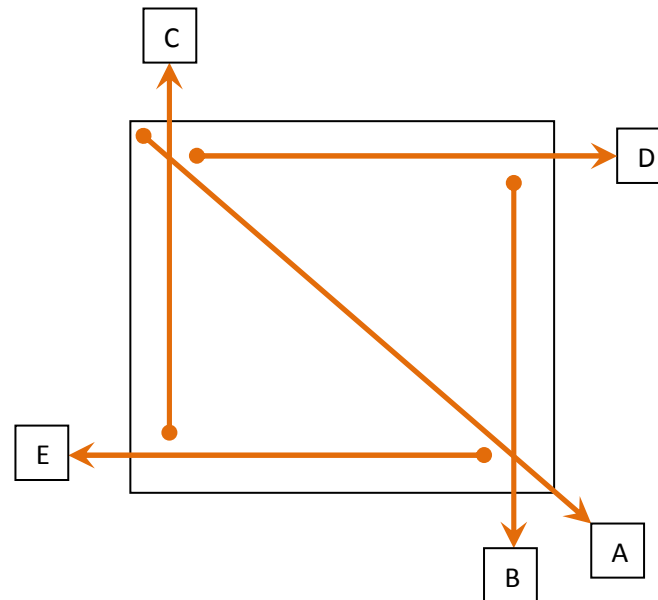


Figure 26: Main curves and their directions in the Probability Maturity Matrix

### Formulas of the different curves making up the Maturity Probability Matrix

#### Curve A

The most critical curves to establish are the diagonal ones. They show the different probabilities for going one maturity level forward or backward from where ever the part may currently be.

$$\text{Result Total} > 0.5 \\ y = (a^x) - 1 \quad \text{where } x > 0, a > 1$$

$$\text{Result Total} < 0.5 \\ y = (a^{-(x+k)}) - 1 \quad \text{where } 1 = a^k, x > 0, a > 1$$

#### Curve B

The value of curve B increases by design because of the Oblique curves characteristic's, discussed above.

Curve B has a value that increases and with a rate that is also increasing. The rate is dependent on the Result Total value.

#### Curve C

The value of curve C decreases by design because of the Oblique curves characteristic`s, discussed above.

Curve C decreases by value and with a rate that is also decreasing. The rate is dependent on the Result Total value.

**Curve D & E**

Column j = 1 to 5:  $\int (a^x) \{ \text{from } j=i+1 \text{ to } j=5 \} + P_{i=j} + \int (a^x) \{ \text{from } j=1 \text{ to } j=i-1 \} = 1$  (for each row i)

a – depends on Result Total value from stage 1  
 P<sub>i=j</sub> is determined in the “Curve A” part shown above

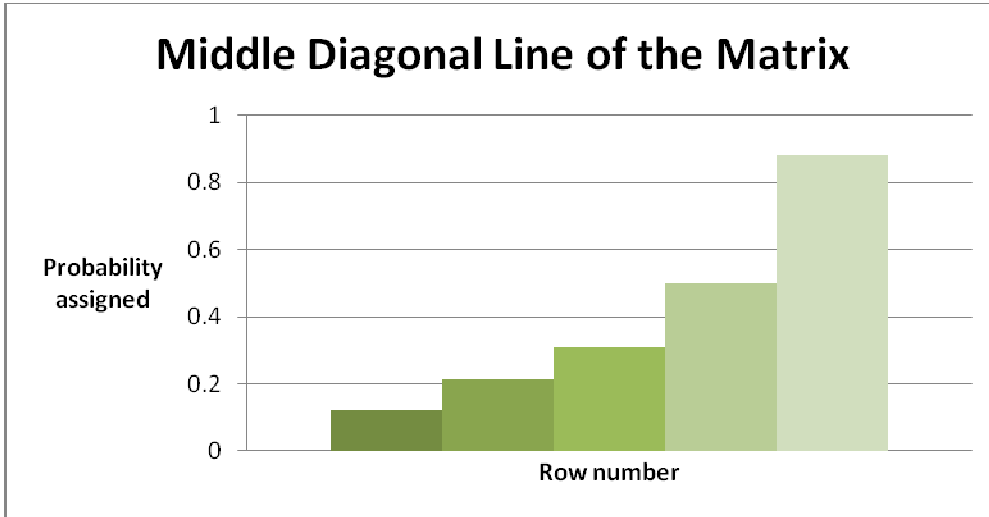
**SIMPLIFIED EXAMPLE no. 3**

1	B	C	D	E	F	G	H
2			0.12	0.47	0.23	0.12	0.06
3			0.04	0.22	0.43	0.21	0.11
4			0.02	0.04	0.31	0.42	0.21
5			0.01	0.02	0.05	0.50	0.42
6			0.01	0.02	0.03	0.06	0.88
7							
8	Factor	Res Tot:	0.88				
9	1.466						

Figure 27: Example of the Probability Maturity Matrix

Column D to H from Row 2 to 6 represents the Probability Maturity Matrix. In this example the matrix is designed for only 5 different maturity levels, to keep it simplistic. The real model can have any amount of rows and equal columns. The main input to start populating the Matrix is the Result Total displayed in Yellow in cell D8.

Graph 2 on the next page, is to assist in understanding the population of the Maturity Matrix shown in figure 27. The graph shows the probability values assigned for the middle diagonal line in the matrix, where i=j. This is the same area as area 2 in figure 24. The graph also shows a clear pattern as the population of the matrix is done according to the formula of the function discussed in the above sections.



Graph 2: Probability in Area 2 of the Matrix

In row 11 the user must specify the rates according to user requirements. The rates are to determine the slopes of the different curves discussed above to populate the Matrix. Cell C13 to C23 gives the different values the factor can be according to the rate just specified. A Factor value is selected based on the value of the Result Total. The Factor is used to determine the middle diagonal line of the Matrix. In the graph below is how the probabilities would look like typically after it has been established according to the curve type and curve rate.

7	B	C	D	E	F	G
8	Factor		= '0'!F8			
9	=C18	=C18				
10						
11	Rate	1.1	Rate		Rate	
12						
13	0	=C14^\$C\$11				
14	0.1	=C15^\$C\$11	Factor	2		
15	0.2	=C16^\$C\$11				
16	0.3	=C17^\$C\$11	1	=D16*\$E\$14	=E16*\$E\$14	=F16*\$E\$14
17	0.4	=C18^\$C\$11	=\$G\$16	=\$G\$16	=\$G\$16	=\$G\$16
18	0.5	1.466				
19	0.6	=C18^C11				
20	0.7	=C19^C11	Factor	2		
21	0.8	=C20^1.1				
22	0.9	=C21^C11	1	=D22*\$E\$20	=E22*\$E\$20	=F22*\$E\$20
23	1	=C22^C11	=D22+O13	=E22+D23	=F22+E23	=G22+F23

Figure 28: Example of calculations performed with rate and factor inputs

3

### Solving the Steady State Probability Matrix

To obtain the Steady State Probabilities of the different maturity levels, MATLAB will be used to do the calculation. MATLAB has a function called “SOLVE”. The function can take multiple functions with multiple unknowns and solve the equations all at once.

#### SIMPLIFIED EXAMPLE no. 3

```
H=solve('0.05*w+0.1*x=w','0.95*w+0.25*x+0.2*y=x','w+x+y+z=1',
'0.4*y+0.55*z=z','w','x','y','z')
m1=H.w
m2=H.x
m3=H.y
m4=H.z
```

Figure 29: The m-file in MATLAB

For the m-file example, values are already added to the function formulation. In the actual model the function will only be in terms of unknowns. A simple interface from excel will then assign values to the necessary unknowns in order to complete the formulation of the function for the calculation.

```
m1 = 0.0145
m2 = 0.1380
m3 = 0.4486
m4 = 0.3987
```

Figure 30: The Result in MATLAB after the model has been run

The results obtained in MATLAB will be in this format. Displayed above is m1 to m4 that gives the different probabilities of a part being in each maturity level 1 to 4. For the actual model this probabilities can be calculated for any amount of maturity levels, depending on the user requirements. An interface will make this data available in excel to further be able to use the data in following stages.



### Shoot point between Engineering Development & Production

The more mature a part becomes, the lower the risk is to transfer the certain part from the Engineering Development Department to the Production Department. Stage 4 will do the calculation to consider important Determinants and according to the risk, determine whether or not it is advisable to transfer the certain part or not. For the purpose of better explanations, the examples will proceed with 10 maturity levels replacing the 4 maturity levels up to now.

EXAMPLE no. 4

A	B	C	D	E	F	H	I
	Maturity Level	Probability	=IF(D4>E4, "transfer", "hold")	Determinants	Risk	Determinants	1 to 10
3						Priority	1
4	m10	0.25	=E16	=1-(0.5-I4/20)-(0.5-I5/20)	30	Time	1
5	m9	0.05					
6	m8	0		=IF(\$F\$4=0,SUM(C4:C13),0)			
7	m7	0		=IF(\$F\$4=10,SUM(C4:C12),0)			
8	m6	0.1		=IF(\$F\$4=20,SUM(C4:C11),0)			
9	m5	0.2		=IF(\$F\$4=30,SUM(C4:C10),0)			
10	m4	0		=IF(\$F\$4=40,SUM(C4:C9),0)			
11	m3	0		=IF(\$F\$4=50,SUM(C4:C8),0)			
12	m2	0.05		=IF(\$F\$4=60,SUM(C4:C7),0)			
13	m1	0.35		=IF(\$F\$4=70,SUM(C4:C6),0)			
14				=IF(\$F\$4=80,SUM(C4:C5),0)			
15				=IF(\$F\$4=90,SUM(C4),0)			
16				=SUM(E6:E15)			

Figure 31: Example of the calculation that triggers the transfer or hold command

Column C is the results obtained from MATLAB in stage 3. F4, displayed in blue, is a user specification. It represents the amount of risk permitted that can be taken with the transfer between the departments. The higher the risk percentage is chosen in F4, the faster the model permits the part to be transferred to the Production Department. The calculation is done by looking at the maturity probabilities above the risk baseline. The risk percentages form the risk baseline. A risk baseline of 30% means all the maturity levels above 70% is being considerate to determine whether or not the transfer could be made. Once the baseline risk is established, the Priority and Time of the part, displayed in light green, plays the final role to determine whether or not to transfer the part. Both the specifications mentioned will get their data update from PDM Link on a continuous basis. The scale is from 1 to 10. 1 represents the highest level of priority with the least amount of time available to execute the transfer. The 10 represents the opposite. For a very high priority and with little time still available, as in the example with a scale of 1, the value returned in E4 is considerably low, almost zero. The value in E4 is then compared with the value calculated according to the risk baseline and the determinants. If D4 is larger than E4, the part gets permission to be transferred. This is displayed in D3 by either showing "transfer" or "hold".

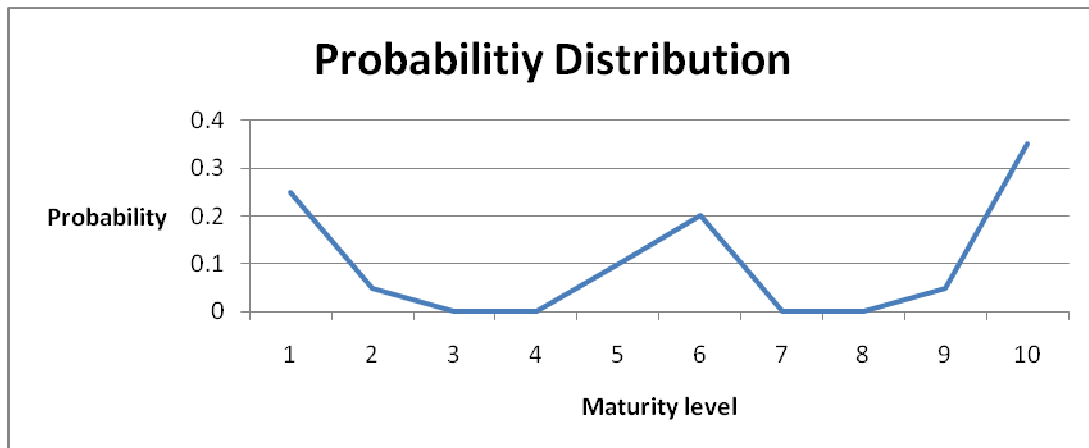


5

### *Maturity level probability distribution and interpretation*

Stage 5 follows on the probability distribution obtained from stage 3. The probability distribution shows the different probabilities of a part being in a certain maturity level. The probability distribution alone is not enough to know for which maturity level provision must be made in the MRP. Thus a further analysis of the probability distribution is done in stage 6.

Below is a graph of how a typical maturity probability distribution could look like



*Graph 3: The Probability distribution at the different maturity levels as from stage 3*

#### EXAMPLE no. 5

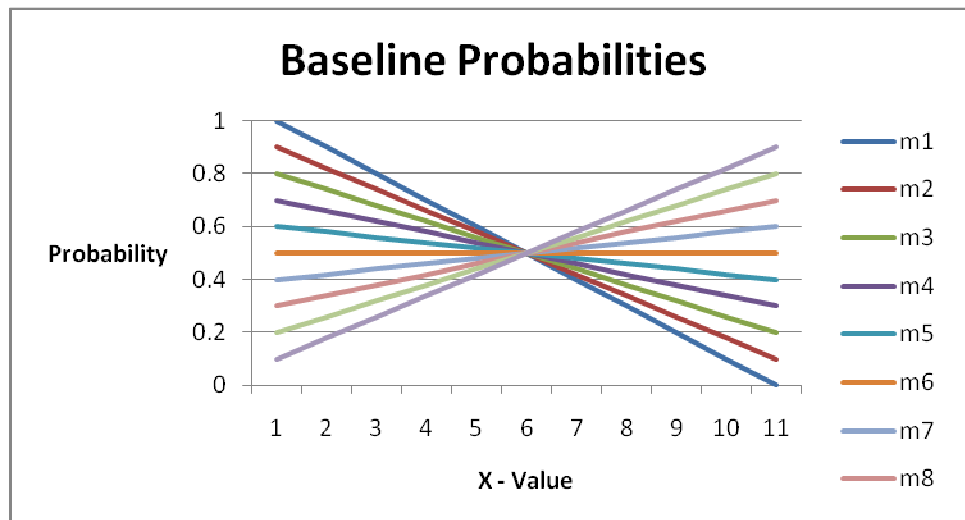
The yellow in figure 32 below is the probability distribution input obtained from stage 3. The distribution is also displayed in Graph 3 above. Although it can be seen that maturity level 10 has the highest probability of occurring, it is not necessary the best maturity level alternative to accordingly make provision for in the MRP. The best maturity level alternative must be established according to the specific part attributes and regardless of how high the specific probability is. To determine the best alternative, 3 additional attributes obtained from PDM Link are considered. The attributes are, the worth of the part, the original production time of the part and the priority of the part. They are displayed in green in the top right corner of figure 32. As the other attributes extracted from PDM Link, these attributes also have a value out of 10. The combined values of the attributes are converted to a value between 0 and 10 displayed in cell W6. In the future more attributes could be added as the model undergoes development and become more advance. Part of the design of the model includes submitting the weights of the different attributes. Currently the model design is set on an equal weight of 33.3% for each the 3 attributes. The combined value of these attributes is 0.8 and is used as the x-value in cell P14.

The Figure below show how the model select the Final Maturity level according to the smallest absolute value

N	O	P	Q	R	S	T	U	V	W
2	Maturity Level	Prob. Distribution	Difference	Absolute value	Minimum	Maturity Level		(Out of 10)	
3	1	0.25	-0.05	0.05	TRUE	1	Part Worth	8	0.267
4	2	0.05	0.21	0.21	FALSE	0	Original Time	8	0.267
5	3	0	0.32	0.32	FALSE	0	Priority	2	0.267
6	4	0	0.38	0.38	FALSE	0			0.800
7	5	0.1	0.34	0.34	FALSE	0			
8	6	0.2	0.3	0.3	FALSE	0			
9	7	0	0.56	0.56	FALSE	0			
10	8	0	0.62	0.62	FALSE	0			
11	9	0.05	0.63	0.63	FALSE	0			
12	10	0.35	0.39	0.39	FALSE	0			
13									
14	x Value	0.800		Output:	1	Final Maturity			

Figure 32: Example of how the Final Maturity level is determined according to inputs

Cell P14 shows how the x value is exactly the same as the combined value in cell W6. The x value determines the values used to calculate the values of column Q. Column Q is the difference between the predefined baselines at the calculated x value, further explained in the next section, and the probabilities in column P. In other words Column Q shows how far the probabilities in Column P are away from the predefined baseline probabilities in the Figures below. The absolute value of Column Q is calculated in Column R. So by taking the minimum value, in Column S, the model can determine in Column T which of the maturity levels is the best alternative to select and make provision for in the MRP. This Maturity level just selected is then the final maturity and the input for the next stage, stage 6.



Graph 4: Graph of the predefined baseline Probabilities for different maturity level

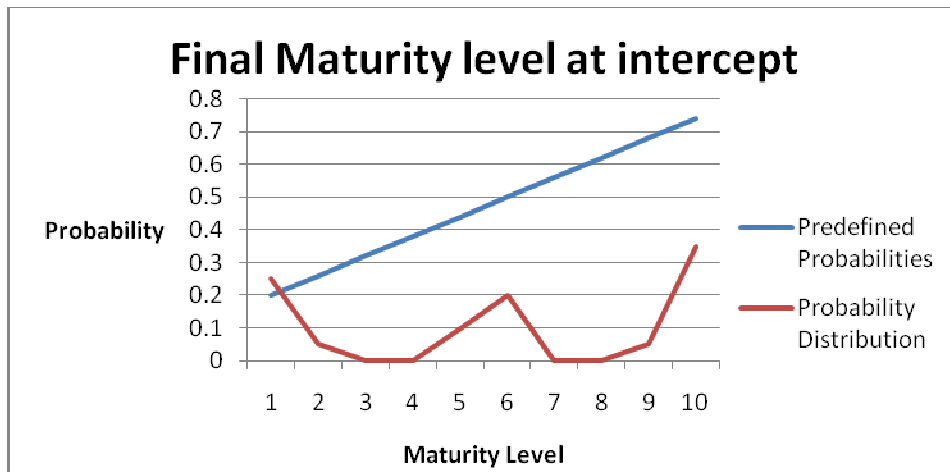
The graph above is a physical representation of the top block values displayed in Table 5. It shows the predefined baseline probability values. The predefined probability values are all the optimum probability levels, for the different maturity levels, to occur at for different values of x. Row 13 is the x axis to determine the applicable column according to the x value specified in the above figure 32 in cell P14. Column B is the y-axis with the different Maturity levels specified.

A column is selected according to the x value from figure 32, and separated from the other column in Column K row 17 to 26. Row N is simply the sum of the columns from row 17 to 26, in order to get the final values of the baseline probabilities. The final value baseline probabilities are then used to perform the calculation of Column Q in figure 32 above. Column Q is the difference between the final value baseline and the probability distribution values.

A	B	C	D	E	F	G	H	I	J	K	L	M	N
2		Start	9	8	7	6	5	4	3	2	1	End	
3	m1	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	
4	m2	0.9	0.82	0.74	0.66	0.58	0.5	0.42	0.34	0.26	0.18	0.1	
5	m3	0.8	0.74	0.68	0.62	0.56	0.5	0.44	0.38	0.32	0.26	0.2	
6	m4	0.7	0.66	0.62	0.58	0.54	0.5	0.46	0.42	0.38	0.34	0.3	
7	m5	0.6	0.58	0.56	0.54	0.52	0.5	0.48	0.46	0.44	0.42	0.4	
8	m6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
9	m7	0.4	0.42	0.44	0.46	0.48	0.5	0.52	0.54	0.56	0.58	0.6	
10	m8	0.3	0.34	0.38	0.42	0.46	0.5	0.54	0.58	0.62	0.66	0.7	
11	m9	0.2	0.26	0.32	0.38	0.44	0.5	0.56	0.62	0.68	0.74	0.8	
12	m10	0.1	0.18	0.26	0.34	0.42	0.5	0.58	0.66	0.74	0.82	0.9	
13	x	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	
14													
15													
16													
17		0	0	0	0	0	0	0	0	0.2	0	0	0.2
18		0	0	0	0	0	0	0	0	0.26	0	0	0.26
19		0	0	0	0	0	0	0	0	0.32	0	0	0.32
20		0	0	0	0	0	0	0	0	0.38	0	0	0.38
21		0	0	0	0	0	0	0	0	0.44	0	0	0.44
22		0	0	0	0	0	0	0	0	0.5	0	0	0.5
23		0	0	0	0	0	0	0	0	0.56	0	0	0.56
24		0	0	0	0	0	0	0	0	0.62	0	0	0.62
25		0	0	0	0	0	0	0	0	0.68	0	0	0.68
26		0	0	0	0	0	0	0	0	0.74	0	0	0.74
27		0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	

Table 5: Predefined Baseline Probabilities for different x values and different maturity levels

The graph below show a physical representation of how stage 6, figure 32, chooses the Final Maturity level as 1 by seeking the smallest difference. The blue line is the predefined probability values obtained from table 4 in column N and selected at the specific x value given in figure 32. Column Q in figure 32 shows the smallest difference is at maturity level 1 and it is 0.05. This is then easily seen on the graph where the two lines lie the closest to one another at number 1 on the x-axis. Although the probability distribution from figure 32 in column P, shown in the red line on the graph below, is the highest at maturity level 10, the optimum maturity level to choose for adjusting the MRP is maturity level 1. The final maturity level and thus the output of stage 6 is maturity level 1.



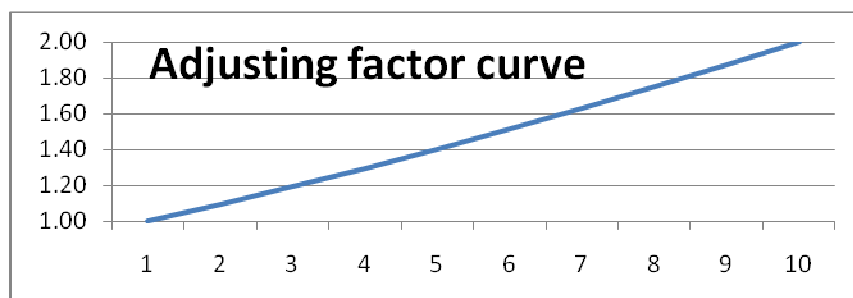
Graph 5: Representation of the Final Maturity level at the interception

6

**Buffer Adjustment in the MRP according to the maturity level of the part**

The result from stage 5 will be used to calculate the buffer adjustment factor in stage 6. The user of the system must specify the starting point of the buffer factor and the amount that the buffer factor increases as the maturity levels increases, purple part in the example. Historical data, discussed earlier, shows that parts slip with anything between 0 and 100 %. Therefore the current setting, displayed in purple, in the Simplified Example has a starting point of 1 and increases with 0.046 to end up at 2.

The buffer adjustment factor increases in the form of a quadratic function as can be seen in graph 6



Graph 6: The buffer adjustment factor increase curve

EXAMPLE no. 6

1	B	C	D	F	G
2		Result	1	=AND(\$D\$2>0,\$D\$2<=B9)	=IF(F2=TRUE,D9,0)
3				=AND(\$D\$2>B9,\$D\$2<=B10)	=IF(F3=TRUE,D10,0)
4	part 001	Adjusting Factor	=G12	=AND(\$D\$2>B10,\$D\$2<=B11)	=IF(F4=TRUE,D11,0)
5		Original time	10	=AND(\$D\$2>B11,\$D\$2<=B12)	=IF(F5=TRUE,D12,0)
6		New time	=D5*D4	=AND(\$D\$2>B12,\$D\$2<=B13)	=IF(F6=TRUE,D13,0)
7				=AND(\$D\$2>B13,\$D\$2<=B14)	=IF(F7=TRUE,D14,0)
8	Level	Factor	Factor ^2	=AND(\$D\$2>B14,\$D\$2<=B15)	=IF(F8=TRUE,D15,0)
9	10	=G16	=C9^2	=AND(\$D\$2>B15,\$D\$2<=B16)	=IF(F9=TRUE,D16,0)
10	9	=C9+\$G\$15	=C10^2	=AND(\$D\$2>B16,\$D\$2<=B17)	=IF(F10=TRUE,D17,0)
11	8	=C10+\$G\$15	=C11^2	=AND(\$D\$2>B17,\$D\$2<=B18)	=IF(F11=TRUE,D18,0)
12	7	=C11+\$G\$15	=C12^2		=SUM(G2:G11)
13	6	=C12+\$G\$15	=C13^2		
14	5	=C13+\$G\$15	=C14^2		
15	4	=C14+\$G\$15	=C15^2		
16	3	=C15+\$G\$15	=C16^2		
17	2	=C16+\$G\$15	=C17^2		
18	1	=C17+\$G\$15	=C18^2		

Weight	0.046
Start Point	1

Figure 33: Selecting the correct adjustment factor according to specified weight and start point

The result from stage 5 is displayed in D2. Column F determines the size of D2 according to a few predefined ranges. These ranges can be narrowed down in the future use of the model to smaller and more accurate portions. Once the range is determined, the model can return the correct factor for the specific range. The model then takes the square of the factor to obtain the final Adjusting Factor. This Adjusting Factor is then displayed in D4, where it is simply multiplied with the original time in D5 to determine the new time in D6. The new time that now contains the time buffer will be used for the MRP planning. The different Adjusting Factors for the different ranges are determined by the predefined weight and start point displayed in purple. The “start point” is the first factor for the maturity level of 10, directly copied into cell C9. The first factor is then used to add to the weight to determine the next adjusting factor. Each time the previous adjusting factor is added to the weight to determine the next factor. All the factors are then multiplied with its own value to give the quadratic effect of the final Adjustment factor explained in the beginning of stage 6 and in graph 6.



## *Capability and accuracy testing of the model*

Once the MRP buffer is added in stage 6 and production is taking place, a capability test must determine how accurate the buffer was estimated. As time goes on any changes to the part can influence times to such an extent that the adjusting buffer is no longer accurate enough to effectively use the adjusting buffer. The capability test will indicate whether it is necessary to recalculate the adjusting buffer or not.

The system user can specify with the Limit factor how sensitive the model must analyze the results for a recalculation. The higher the Limit factor, the less sensitive the analysis is conducted. The factor is multiplied with the original time to obtain the window in which the process time can vary. The window is all the allowed values that the actual time of the part can take on to fall within the required accuracy of the Model. For a larger factor the window of allowable options becomes larger. The Limit factor also by design changes according to part specifications such as lead time, available time and the size of the adjusting factor. As the lead time and time available decreases, the Limit factor also decreases by a small portion. For a bigger Adjusting factor the Limit factor will also become smaller. This is just to keep calculations in perspective with the rest of the model and realistic with real world scenarios.

The moment the actual progress time of the part exceeds the allowed time limits of the window to either side, the model takes the current part characteristics and feed them back to stage 1 for a complete recalculation of the buffer adjustment factor through all the model stages.

EXAMPLE no. 7

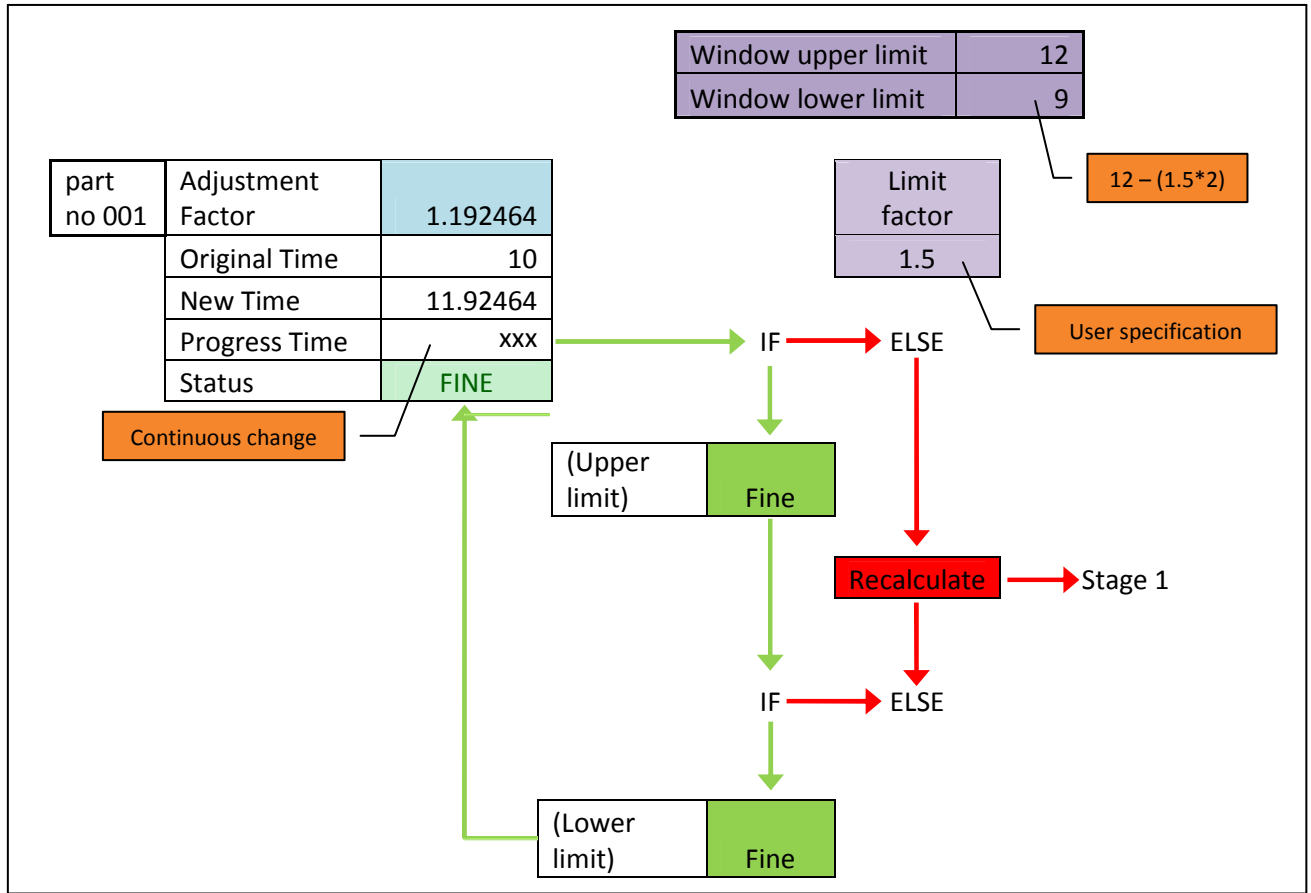


Figure 34: Capability testing with the specified Limit Factor

As an example, Part no 001 has an original lead time of 10 with an adjusting factor of approximately 1.2. Therefore the new time in the MRP will be adjusted to approximately 12 units. With a limit factor of 1.5 the window of allowable values can be calculated as from  $12 - (1.5 * 1.2)$  and up to 12. With two loops indicated in red and green, the model will continuously make sure the progress time of the part fall within the window of 9-12 units. If the progress time meets both the upper and lower limit specifications, indicated by the two blocks displaying “fine” in green, the status of the part will be indicated as fine. Otherwise the status would indicate “recalculate” where the current characteristics of the part are send back to stage 1 indicated in the red arrows.

## 12.6 How the process problems are solved with the new Model capabilities

With the capabilities and outputs of the newly designed Maturity Model, both of the main problems identified during problem formulation can be addressed. The problem of not having a stable Production plan is solved to some extent by adding a buffer. The buffer is continuously managed and performing capability tests to assure accuracy and effective use of the model. The problem of not having knowledge of when to transfer the BOM if time is pressing is solved by monitoring when a BOM is mature enough to transfer. This is done according to part inputs from PDM Link, that, when the part is above some certain required point, state the transfer of the BOM can now be made. The figure below shows how the process is changed with the new model possibilities. All the areas of the process that changes are indicated by red while the areas that stay the same remain in green.

### Old Process:



Figure 35: The old process

### New Process:

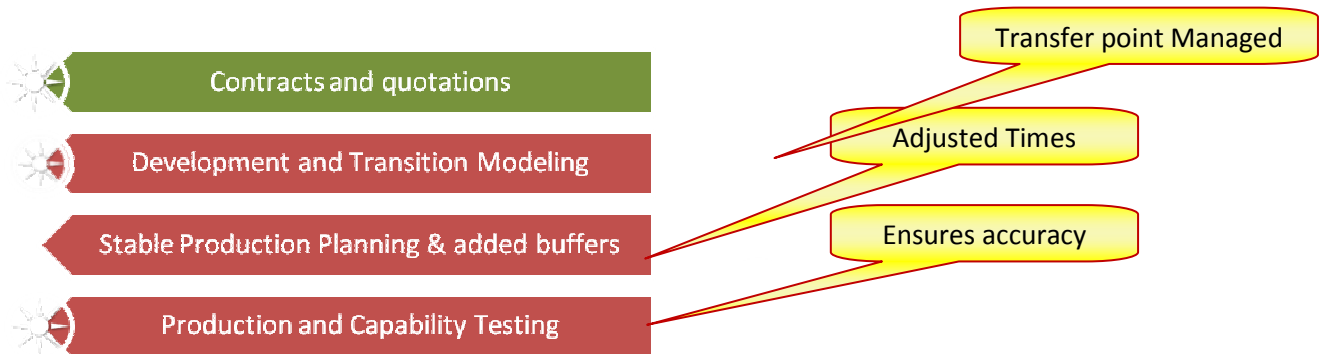


Figure 36: The new process with improvements



## 13. TESTING

In order to assure the model and software meets design requirements and that it fulfills its intended purpose, some verification and validation steps had to be taken.

### *13.1 Verification*

Looking back to the original project aim one can see what the design requirements and specifications expected from the newly designed model were. With some evaluation it is possible to establish that all of the system requirements as been met with the newly designed Maturity Model solving the two main problems. With the two main problems been managed by the Model, the process of missile development is now able to flow and function more effectively and achieves the ultimate aim of higher productivity.

One of the methods used to confirm verification, is by Static Testing.

#### **Static Testing**

Static testing is done without running the model. It is mainly to check the common sense of the algorithm, calculations and actions that make up the model.

The static testing was conducted by first checking all the syntax of coding and manually checking for any errors in the model calculations. Further testing was done by walking through model execution and by inspections of the model stages.

It was confirmed that all the coding, calculations and executions of the model function according to initial design requirements and specifications.

The model has been build correctly and according to specifications and requirements imposed at the start. The model can now be correctly implemented.

#### **Capability Testing**

The model has its own capability testing stage to check its own performance during model execution. The capability test takes the main output of the model, namely the adjusting factor, and checks whether or not the estimation of the adjusting factor, for the specific part, were done accurately or not. This process is performed on a continuous basis to immediately detect exceptional parts that was not initially correctly

estimated and planned for in the MRP. The complete explanation of the capability test is in section 12.4.

## ***13.2 Validation***

Validation is a necessary to establish to what degree the model and associated data are accurately representing the actions of an experienced person performing the work in the real world. That will ensure that the model meets the intended requirements and fulfill its intended usage.

Validation can further be exercised by making use of Dynamic testing methods

### **Dynamic Testing**

Dynamic testing is mainly to test software such as the newly designed Maturity Model. The model coding behaviour must be tested dynamically by looking at the physical response of the model as the inputs to the model vary. That will require the software of the Model to be ready and able to execute maturity level determination. The more the software is used in executions of maturity level determinations, the better the validation becomes. The dynamic testing could also include part testing, model integration testing and acceptance testing.

Once dynamic testing is partly completed, the software of the Maturity Model will be able to satisfy the user needs and the intended needs of the model.

## PART C

### 14. RECOMMENDATION

It is recommended that the model be implemented.

Once the model is capable of executing part maturity determinations, the input information from PDM Link could further be exploited. In stage 2 improved algorithms could be designed to increase the accuracy of the model. Finally all user specifications and model outputs could be refined to upgrade the model to more advance capabilities.

Training on the use of the model is recommended to assure successful execution of part maturity estimations. Most of the training would consist of using and managing the model through its interfaces.

### 15. CONCLUSION

Aligning the Engineering Development and Production Department is a difficult task since their operational environment is completely different. As far as technology go, the environment will always bring forth changes to production. By managing the changes, positive results could possibly be achieved instead of being unprepared. The changes could be managed and planned for by monitoring the maturity levels of each component and weighing it up against time availability and other attributes for the specific component. This would help manage the transfer point between Engineering Development and Production and once in production help populating a more stable MRP and MPS by adding a time buffer. It is recommended that the maturity levels are monitored with the model developed as part of this report to alleviate the current erratic planning in the production department. The model should be refined over time by using practical results.

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## Appendix

**Figure A1: Organization Departments Structure**

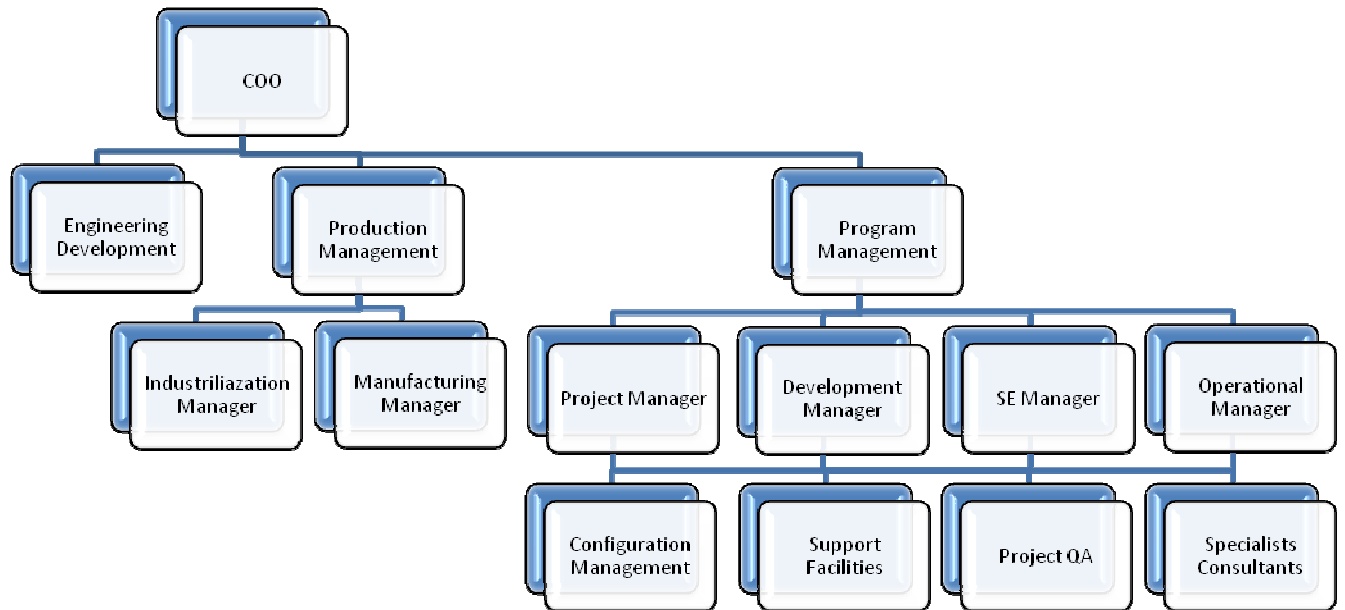


Figure A2: Change Cycle Process and system interactions

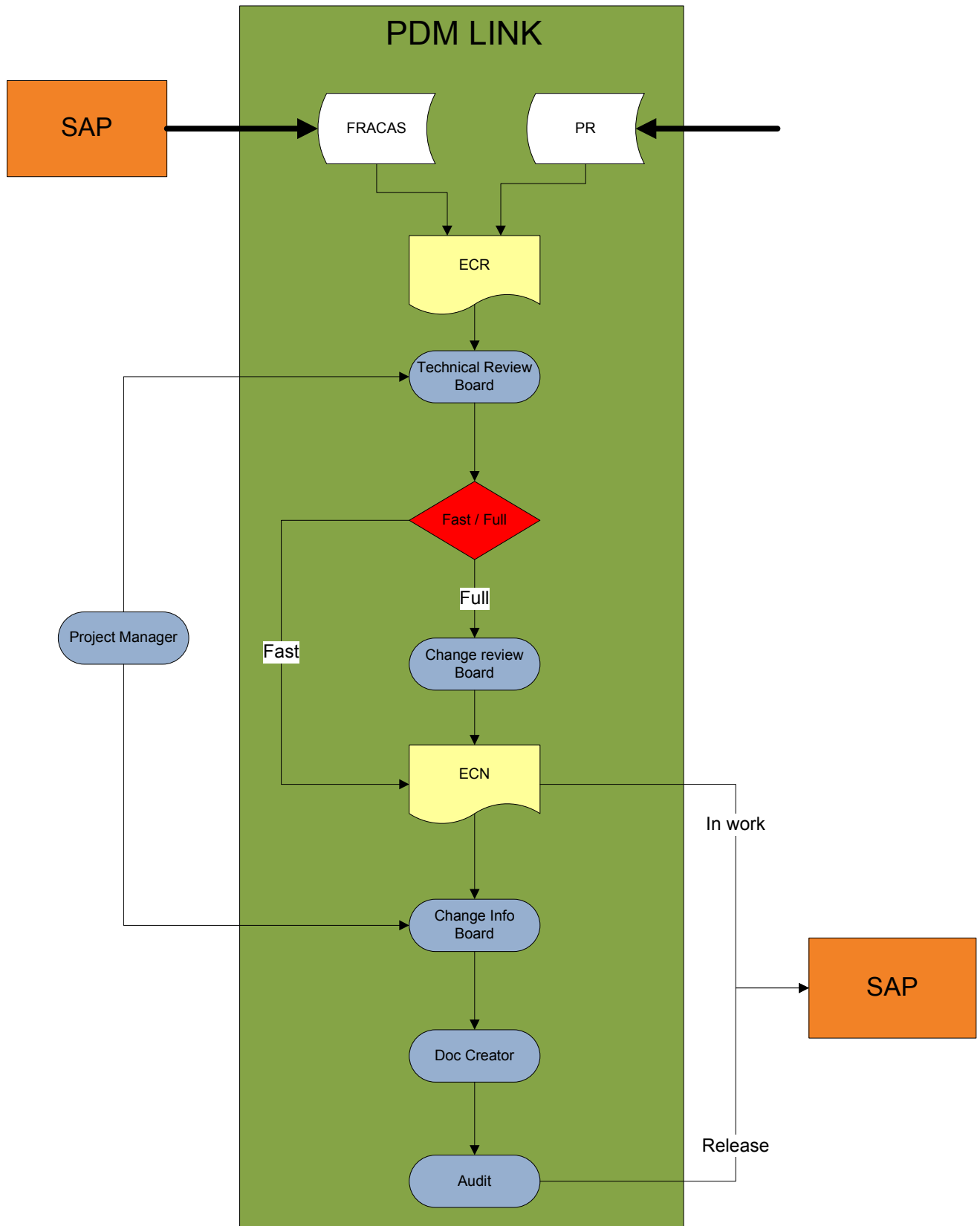


Figure A3: Document Structure Flow

Documents Structure Flow

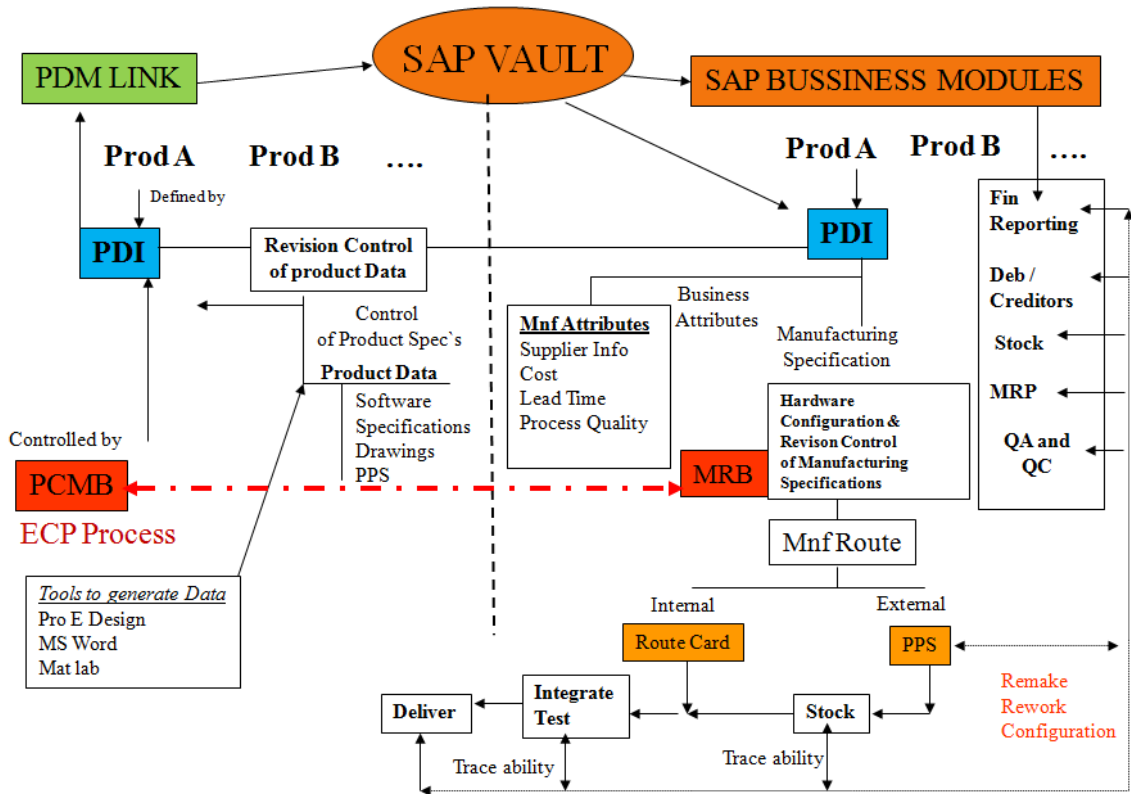


Figure A4: Production Process



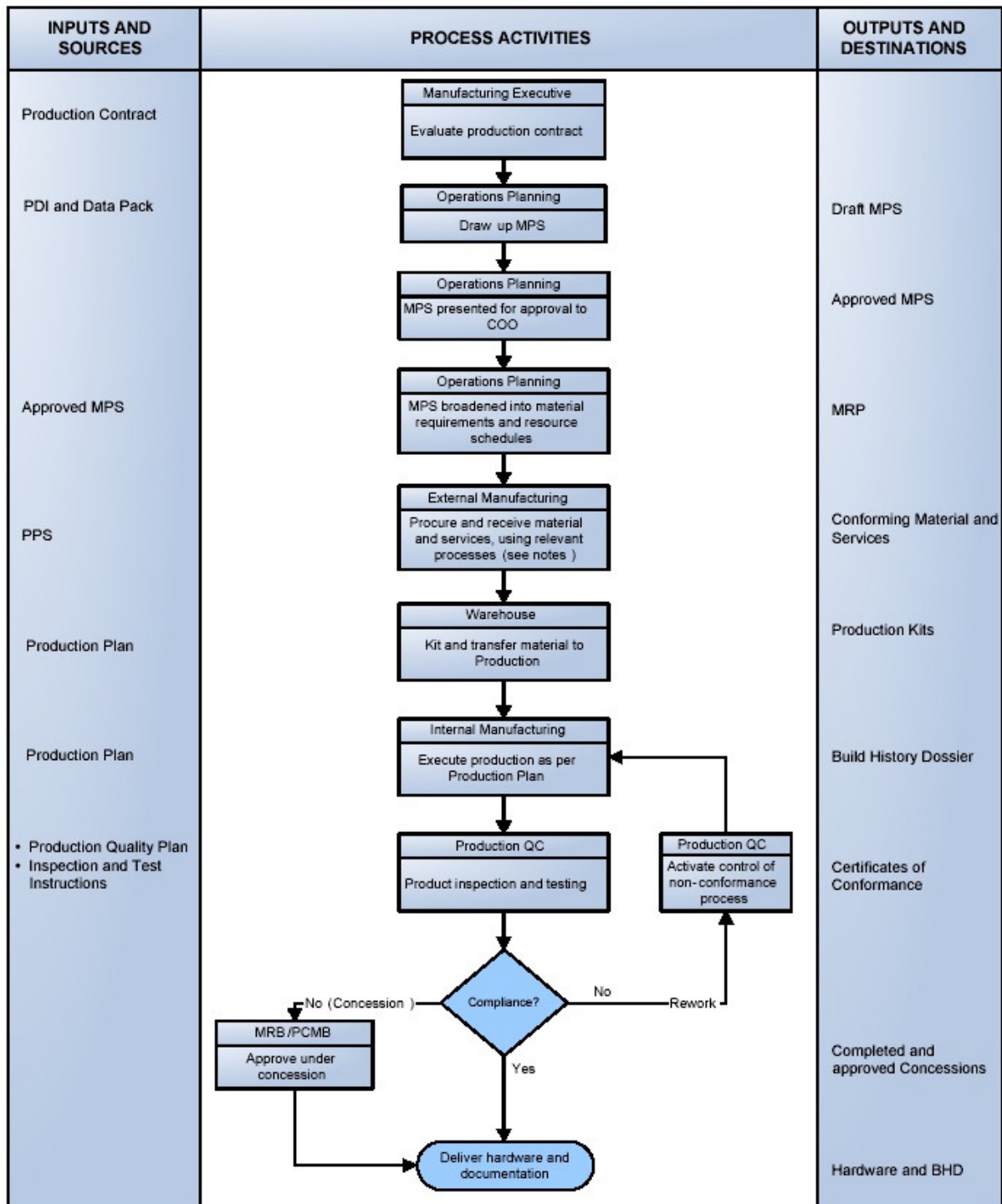


Figure A5: Product life cycle

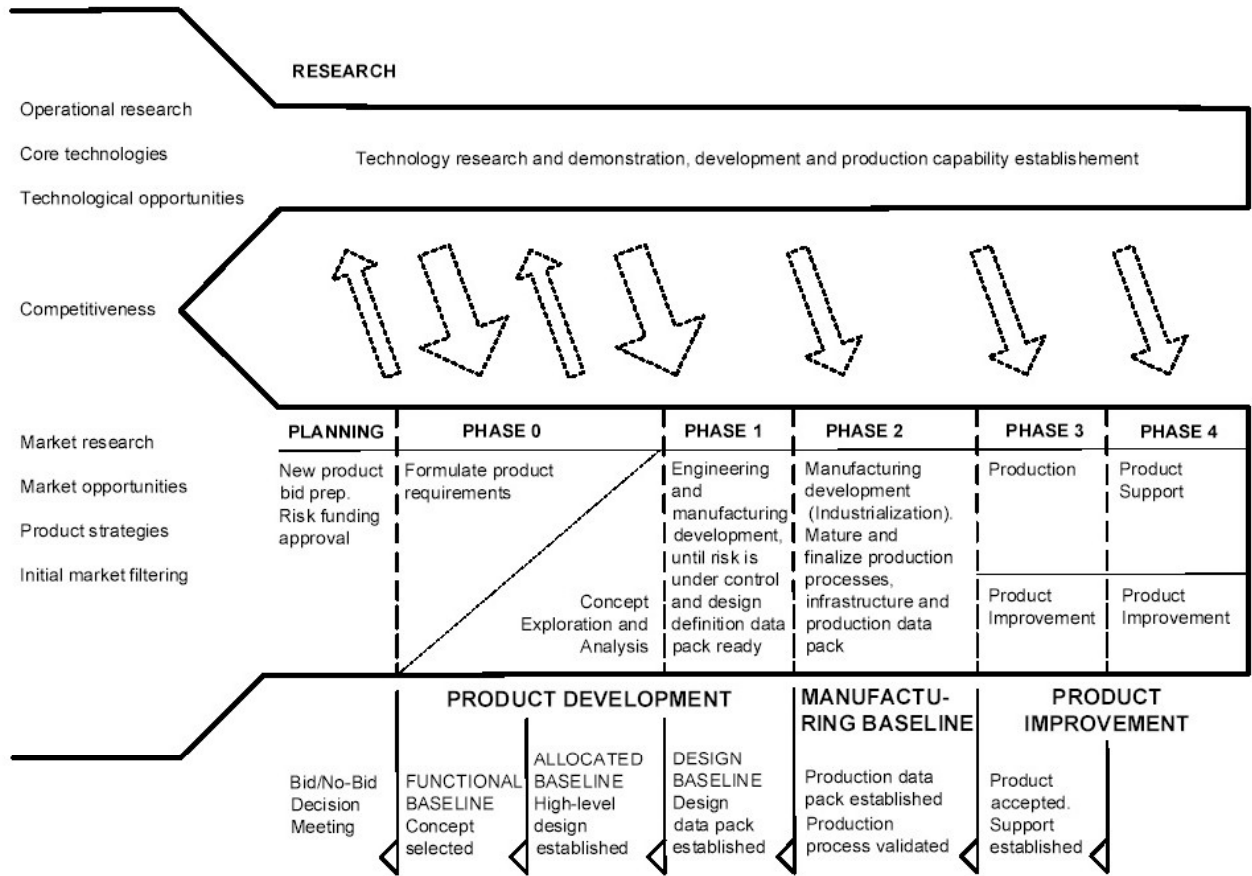


Figure A6: Industrialization Process

Input (Source)	Industrialization Process	Output (Destination)
<ul style="list-style-type: none"> <li>• Programme/Project Plan <i>(Programme Manager)</i></li> </ul>	<div style="border: 1px solid black; padding: 5px; text-align: center;">Industrialization contracting</div>	<ul style="list-style-type: none"> <li>• Industrialization strategy</li> <li>• Work Breakdown Structure and Work Authorization</li> <li>• Approved schedule <i>(Development Manager/Production/Test Equipment/Production Engineering/Fin Manager)</i></li> </ul>
<ul style="list-style-type: none"> <li>• Product Specification <i>(Programme Manager/System Engineer)</i></li> <li>• Design files <i>(System Engineer)</i></li> <li>• Design data pack <i>(System Engineer)</i></li> <li>• Hardware requirements <i>(System Engineer/Programme Manager)</i></li> </ul>	<div style="border: 1px solid black; padding: 5px; text-align: center;">Mature the design</div>	<ul style="list-style-type: none"> <li>• Qualification Report</li> <li>• LSA Report</li> <li>• Prototype hardware <i>(System Engineer/Programme Manager)</i></li> </ul>
<p>Configuration Management Plan <i>(Configuration Manager)</i></p>	<div style="border: 1px solid black; padding: 5px; text-align: center;">Establish a produceable data pack</div>	<ul style="list-style-type: none"> <li>• Released product definition <i>(Programme Manager)</i></li> <li>• Approved PDI <i>(Programme Manager/Procurement)</i></li> </ul>
<ul style="list-style-type: none"> <li>• Product Data Pack <i>(Programme Manager/System Engineer)</i></li> <li>• Production strategy <i>(Production Manager/Programme Manager)</i></li> <li>• Test requirements and strategy <i>(System Engineer/Test Equipment Manager)</i></li> <li>• Quality Plan <i>(Quality Manager)</i></li> </ul>	<div style="border: 1px solid black; padding: 5px; text-align: center;">Establish a qualified production process</div>	<ul style="list-style-type: none"> <li>• Production process documented</li> <li>• Test equipment and procedures</li> <li>• Manufacturing and assembly instructions</li> <li>• Quality requirements</li> <li>• Inspection plan and equipment</li> <li>• Tools, jigs and fixtures</li> <li>• Packaging, handling, storage and transportation definition.</li> </ul> <p><i>(Production Manager, Quality Manager, Procurement Manager)</i></p>
	<div style="border: 1px solid black; padding: 5px; text-align: center;">Know-how transfer</div>	<ul style="list-style-type: none"> <li>• Commissioned production process, equipment and production process documentation. <i>(Production Manager, Quality Manager, Programme Manager)</i></li> </ul>

Figure A7: Document Structure

