PATTERN BASED SYSTEM ENGINEERING (PBSE)- PRODUCT LIFECYCLE MANAGEMENT (PLM) INTEGRATION AND VALIDATION

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I dedicate this work to my family, which is the strongest pillar of my life.

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ABBREVIATIONS

SE	System Engineering
MBE	Model Based Engineering
MBSE	Model Based System Engineering
PLM	Product Lifecylce Management
INCOSE	International Chapter of Systems Engineering
PBSE	Pattern Based System Engineering
IIOT	Industrial Internet of Things
SDPD	System Driven Product Development
SLIM	System Lifecycle Management
SYSML	Systems Modelling Language
MBPLE	Model Based Product Line Engineering
BMIDE	Business Modeler Identity Developing Environment
COTS	Commercial Off The Shelf
SOA	Service Oriented Area
WAN	Wide Area Network
LOV	List Of Values
BOM	Bill Of Materials
CAD	Computer Aided Drawing

ABSTRACT

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Mass customization, small lot sizes, reduced cost, high variability of product types and changing product portfolio are characteristics of modern manufacturing systems during life cycle. A direct consequence of these characteristics is a more complex system and supply chain. Product lifecycle management (PLM) and model based system engineering (MBSE) are tools which have been proposed and implemented to address different aspects of this complexity and resulting challenges. Our previous work has successfully implemented a MBSE model into a PLM platform. More specifically, Pattern based system engineering (S* pattern) models of systems are integrated with TEAMCENTER to link and interface system level with component level, and streamline the lifecycle across disciplines. The benefit of the implementation is two folded. On one side it helps system engineers using system engineering models enable a shift from learning how to model to implementing the model, which leads to more effective systems definition, design, integration and testing. On the other side the PLM platform provides a reliable database to store legacy data for future use also track changes during the entire process, including one of the most important tools that a systems engineer needs which is an automatic report generation tool. In the current work, we have configured a PLM platform (TEAMCENTER) to support automatic generation of reports and requirements tables using a generic Oil Filter system lifecycle. There are three tables that have been configured for automatic generation which are Feature definitions table, Detail Requirements table and Stakeholder Feature Attributes table. These tables where specifically chosen as they describe all the requirements of

the system and cover all physical behaviours the oil filter system shall exhibit during its physical interactions with external systems. The requirement tables represent core content for a typical systems engineering report. With the help of the automatic report generation tool, it is possible to prepare the entire report within one single system, the PLM system, to ensure a single reliable data source for an organization. Automatic generation of these contents can save the systems engineers time, avoid duplicated work and human errors in report preparation, train future generation of workforce in the lifecycle all the while encouraging standardized documents in an organization.

1. INTRODUCTION

Technological development is considered to be one of the most important factors to affect the growth of an economy. Back in the 1950s, Manufacturing in the United states was responsible for about 19% of gross domestic product (GDP) and employed 30% of the workforce [1] and this number has significantly dropped by the year 2011 where it is responsible for 12% of GDP and employs 11% of the workforce [2]. This sector has been still in recession and many manufacturing facilities have advanced their way towards developing countries. There is a strong need to find a way to stop this, boost the countrys economy and remain a prominent force in the 21st century as well. One way towards this goal would be by major advancement in technology which solves increasing complexity of modern systems and the process of decision making easier. The increasing complexity is the result of poor or no compatibility between various technological tools. Thus integration of these tools would be a great challenge and the resulting advantages are many. To support this statement, 6.573 billion things were connected to internet in the year 2014. This number will increase to over 25 billion in 2020 [3] which will have direct and tremendous impact on the future of manufacturing. This also comes as a possible solution to the frequently described problem of increasing complexity, explosion of variants due to technological progress and increasing rate of changes in manufacturing processes.

1.1 Problem Definition

Most of the modern complex systems we work around are smart systems that perform according to requirements and with capabilities to predict, react and social (communicate with each other and us). Industrial Internet of things (IIOT) and industry 4.0 are two increasingly discussed strategies helping to make manufactures more productive. [4] There is a need to develop a mechanism which helps product managers with short-lived market windows and diverse product requirements without compromising on the quality of the final product. PLM provides the best way to effectively involve multi-disciplinary fields and ensure that the product and the associated lifecycle approaches are optimized. The current system engineering trend is to drive away from document based approach and towards integrated models for managing the complexity. Model based methodologies yield significant benefits such as early identification of unexpected design challenges, better understanding and documentation of designed behavior. This is a major reason why Model Based System Engineering (MBSE) is of growing importance in system design. But, the critical success factor is to manage alignment through requirement cascade and dependency management, not to try to align all requirement to a single model, but to an interdependent ecosystem. Hence integration of MBSE-PLM is important where one can rely on this interdependent ecosystem.

Patterns knowledge and benefits drives from Model based System Engineering (MBSE). When PBSE is used for a new project there is a strong foundation provided from an preceding pattern or number of patterns. PBSE has been addressed and carried out on different enterprises and domain. [5].

The gap addressed in this study is the lack of model-based continuity of system engineering activities from the early phases (proposals and conceptual design) to detailed phases (detailed design, development and delivery). There are also constraints in the transfer of knowledge across the system lifecycle, as the knowledge is within the mind of a system engineer. This gap exists because the tools used for systems modeling and analysis are different in each phase. There are no common grounds for an entire lifecycle for effective knowledge transfer. We introduce PBSE-PLM integration in our efforts to easy understanding of complex systems. This integration is done to ensure all possible information exchange (Requirements, feature model/variants, test cases, process and workflows), Ensure traceability, integrated tool chain and have a single or integrated data and configuration management platform.

1.2 Literature Review

Systems engineering approach is only complete when all the process, items etc involved in a system are documented. This gets increasingly difficult in modern manufacturing world as the products or systems are continuously evolving. There is high level of complexity that comes along with this evolution. Complexity in designs, behaviours, interdependencies, decision making etc involving implementations are a common problem modern system engineers face. These problems are in varied domains of a particular system and this entire information is covered by a system engineer, therefore it is very important to have transfer of knowledge for next generation or future engineers which requires very in-detail and precise documentation. In recent times, Models were created to better explain a complex system. Also it is much easier to explain a system using figures than including hundreds of pages of documents.

1.2.1 Model Based Engineering

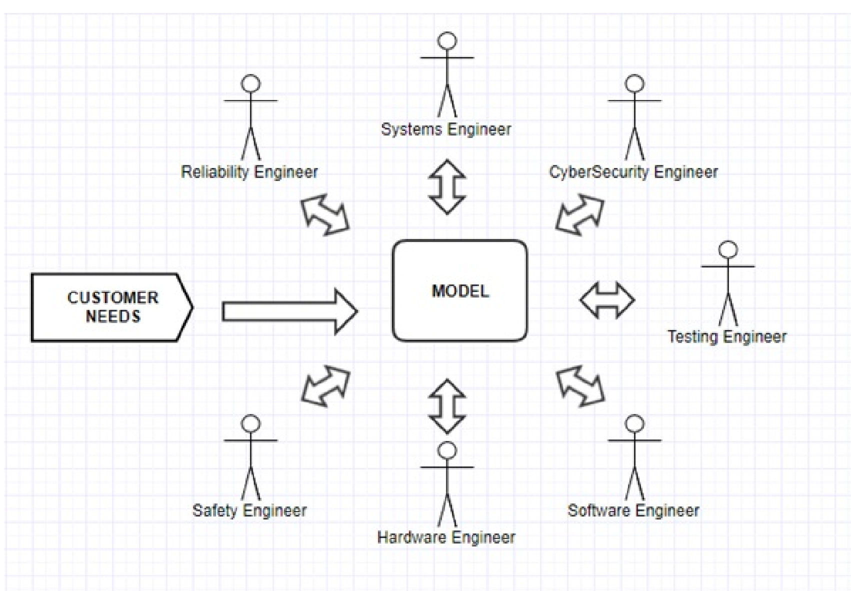


Figure 1.1. Model Based Engineering

Model-Based Engineering (MBE): An approach to engineering that uses models as an integral part of the technical baseline that includes the requirements, analysis, design, implementation, and verification of a capability, system, and/or product throughout the acquisition life cycle [6]. The models can reflect some aspects of a problem in reality, but in a more orderly form, and can be explained by theories. The objectives of a model range from facilitating clear understanding, to aiding in decision making, examining what if scenarios, to explaining, controlling and predicting events. Feeding from the MBE concept comes Model Based System Engineering (MBSE) which is specifically associated with system engineering which also includes behavioural analysis, system architecture, requirement traceability, performance analysis, simulation, test, etc. Model Based System Engineering (MBSE) changes and improves how we represent systems [7]. Key characteristics of a MBSE process is the continuous loop, which ensures that at the time of delivery, even though the model becomes more complex than it was at beginning, it still has clear order and is easy to understand. MBSE is the formalized application of modelling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing through development and later life cycle phases [8]. MBSE is goal driven, the goal here is to eliminate document based tradition by using models as a form of representation. The main advantages MBSE posses is that it helps increase productivity, improving quality, improving communication and significantly reduce risk.

Above Figure 1.1 depicts the activities and related relationships that generally characterize the overall process, from customer needs to the final system solution. In the last decade, large-scale system projects have been created using different lifecycle development models. They often use their own lifecycle patterns, but the most common lifecycle models are Royces Waterfall model [9], Boehms spiral model [10], and Forsberg and Moozs Vee model [11]. Each defines the lifecycle differently. All these process model approaches are continual, an iterative operation is done to achieve a suffice result.

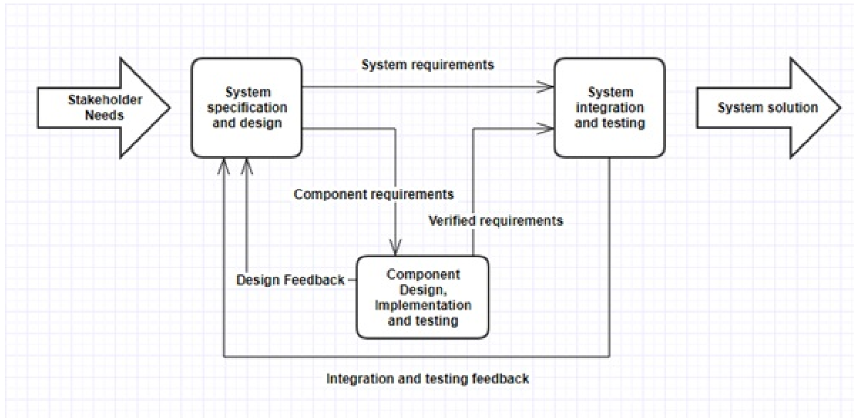


Figure 1.2. Stakeholder Needs to System Solution

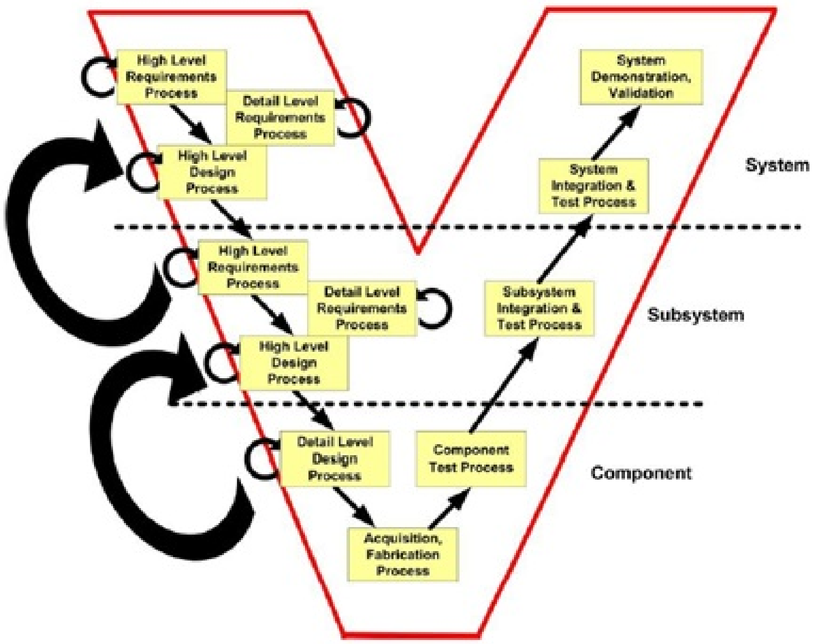


Figure 1.3. Vee Domain Diagram

Global efforts are working toward the exchange and interpretation of model data by machines and people, for purposes of simulation, procurement, fabrication, code generation, etc [12].

The whole idea of a effective model is to serve the needs of model interpreter. If the goal is to communicate with a large community or serve a large company with the idea of modelling then it is that important to make the system easier to understand, making model interpreters job easier.

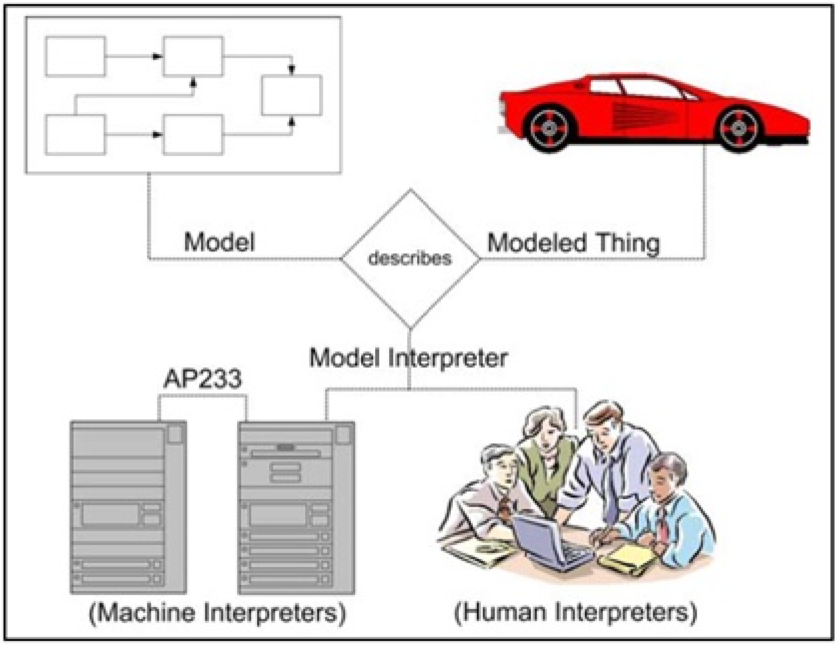


Figure 1.4. Model Interpreters

But, there are few limitations of MBSE such as the domain is fixed when a product is designed with respect to a model. This can lead benefits to a some cases where you deal with a family of products, as system engineers shall not have to start from scratch and can rely on some strong foundation. But, if a new product has evolved significantly the existing model can not be used to designed this system as there is a risk of diverging fundamental issues which are essential to incorporate new features. An SE team that uses MBSE tools and practices improves productivity within the team but finds itself further isolated from the rest of the engineering organization and processes. This is due to complex MBSE tools being used by a small number of engineering specialists whose models are not easy to disseminate and not easily understood by the rest of the organization preventing the intent of the systems engineers from being followed to its fullest.

1.2.2 Integrated MBSE Driven System Development and Management

MBSE is not subject to the standard change control process, because MBSE lacks integration into the overall design and configuration management process. To counter these varied limitations the current trend is to integrate MBSE with a powerful PLM tool which can manage the entire lifecycle, effective communication, ease of understanding the system and all the while assuring quality of the delivered product.

1.2.3 Current Trends

1. In today's modern world, components and products have become systems where product designs require a mix of hardware, software, electronics and/or firmware. If MBSE is not tightly linked to PLM, product quality issues will emerge, putting brands, companies and their stakeholders at risk. A fully integrated MBSE PLM capabilities that is supported by a computational continuum provides Integrated model-based system driven product development and management,-Siemens, an industrial leader, has referred to such integration as SDPD (Systems Driven Product Development) Framework that is poised to address the current challenges of modern manufacturing (characteristics of Industry 4.0) by enabling the digital enterprise.

SDPD builds a solution by integrating different engineering disciplines involved in a single process/system. It is defined as an open and modular solution to cross-domain collaborative product development, manufacturing and in-service support which fully integrates modelling and simulation to predict product and process performance across a wide range of disciplines and domains, including mechanical, electrical, software and controls. It combines systems engineering with an integrated product definition and the ability to unify product development framework with manufacturing and shop floor operations. There are five key characteristics to SDPD.

First, it involves multi-level, multi-domain, and multi-scale models. For example, 1 Dimensional system modeling and simulation can be used to predict operating point and scenario to manage transient I/O boundary conditions (e.g. temperature,

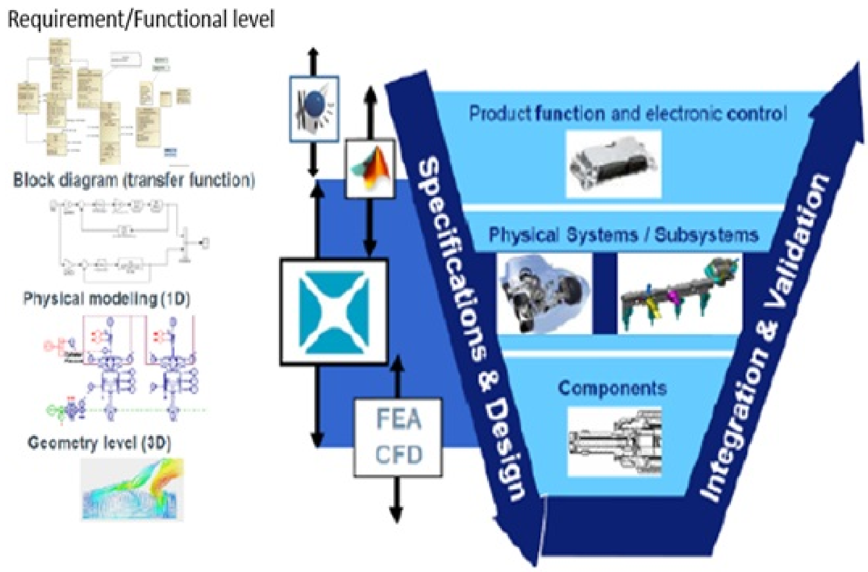


Figure 1.5. Multi-level, Multi-domain and Multiscale Models

pressure, flow rate, control, etc.), while, 3 Dimensional component (or subsystem) modeling and simulation can be used for zooming in on components in the 1 Dimensional sketch to ensure the simulation quality at a geometric resolution (e.g. Jet forces, pressure gradient, flow coefficient, etc.)

Second, requirements drive the development process. In the design team, system analysts develop requirements based on customer needs to build products that customers want. Requirements management works in conjunction with system modeling and system simulation to both design and test the system model.

Third, SDPD requires multi-level and effective communication. For example, system analysts use requirements to communicate decisions to systems designers and system testers. System designers communicate how the system model should be tested and what targets should be made in a design validation plan. System designers and system testers communicate design issues, feasibility issues, and requirement assessment issues to each other and the system analysts.

Fourth, SDPD is characterized by data and information management and reuse to support cross-engineering domain. In fact, PLM provides a cross-domain platform to capture and map the relationships needed to make global and cross-domain design de-

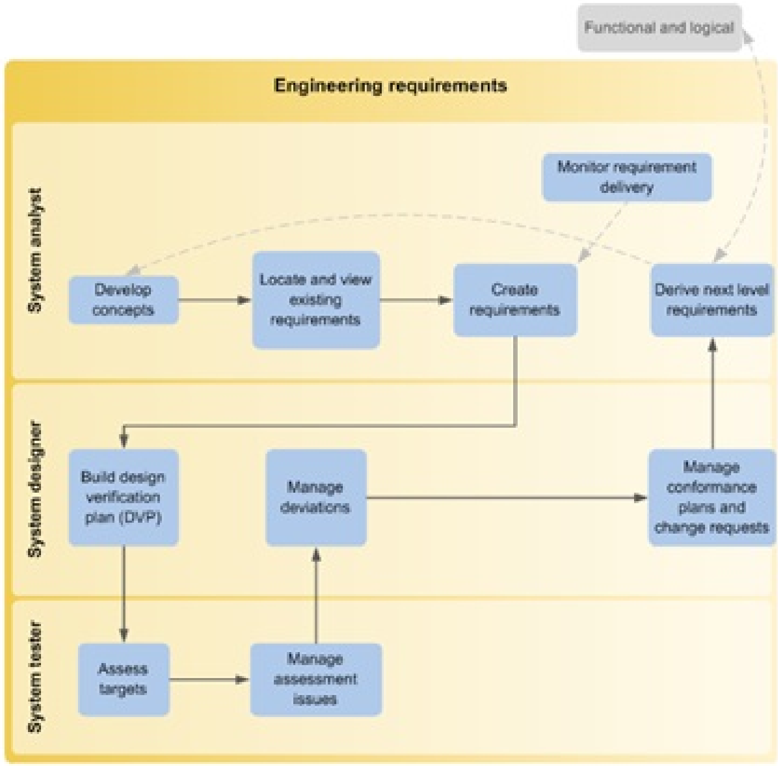


Figure 1.6. Requirements Drive Process

cisions required to develop multi-domain products or systems. Finally, SDPD is characterized by traceability across all aspects of the multi-domain product. It provides development team continuous insight into conformance to requirements throughout the product lifecycle.

2. Intercax LLC is an engineering software company specializing in the integration of complex data models for systems engineering. It is a pioneer and trusted global innovator in the field of Model-Based Systems Engineering. Their product SLIM (System Lifecycle Management) is envisioned to provide capabilities that combine the strengths of model-based systems engineering and product lifecycle management (PLM) [13]. SLIM has been designed as a MBSE workspace on a strong PLM platform. It uses Sysml (Systems modelling Language) as a tool to synthesize from the beginning of system development.

3. Another company PTC, a computer software company that provides solutions which help transform how products are created and serviced, helping compa-

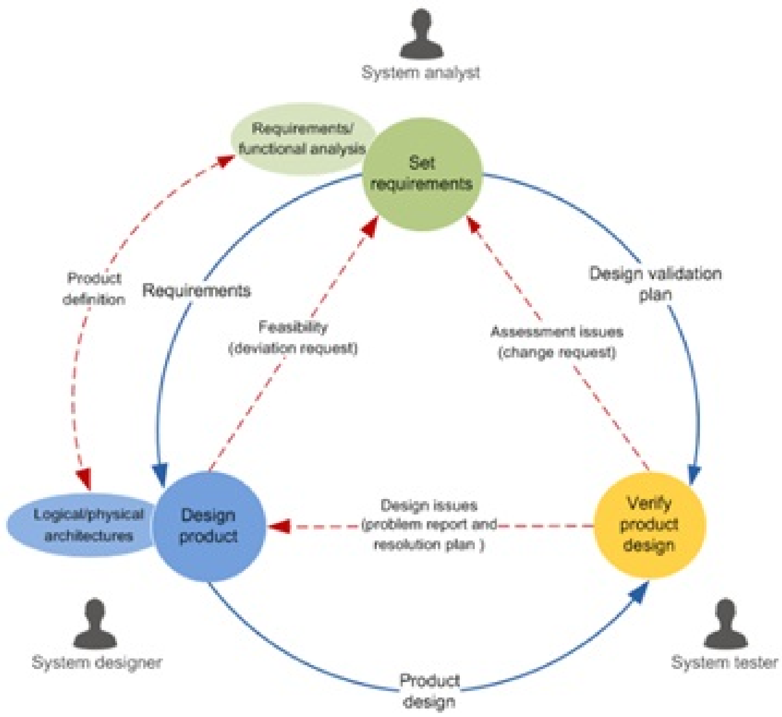


Figure 1.7. Effective Communication Cycle

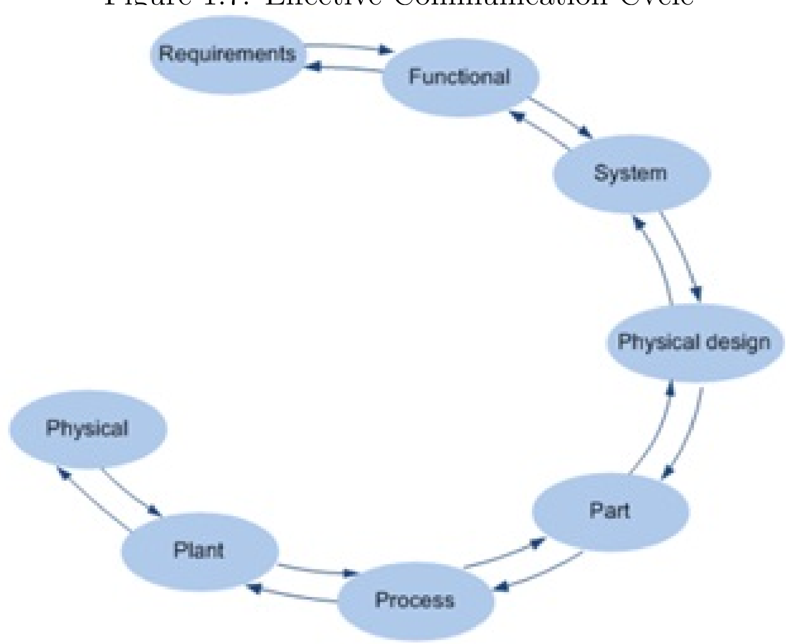


Figure 1.8. Traceability

nies achieve product and service advantage has also taken significant efforts in this area. [14] This study believes that while PLM enables organizations to manage the

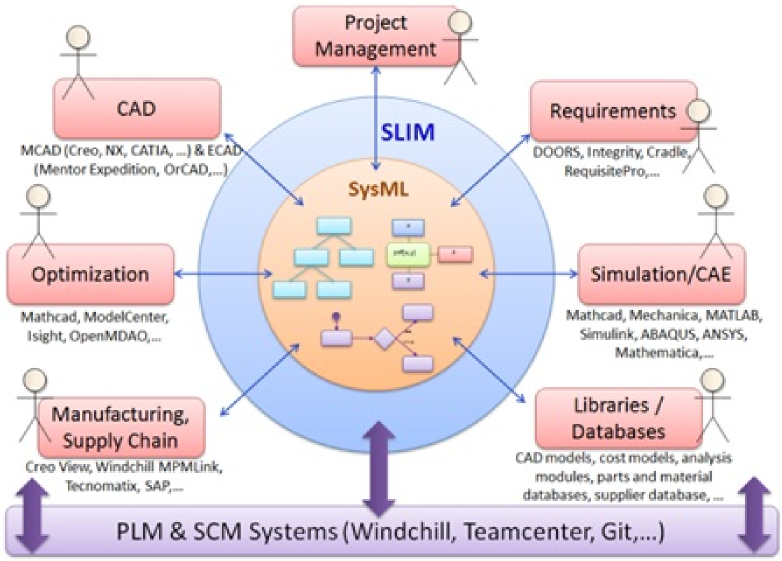


Figure 1.9. System Lifecycle Management

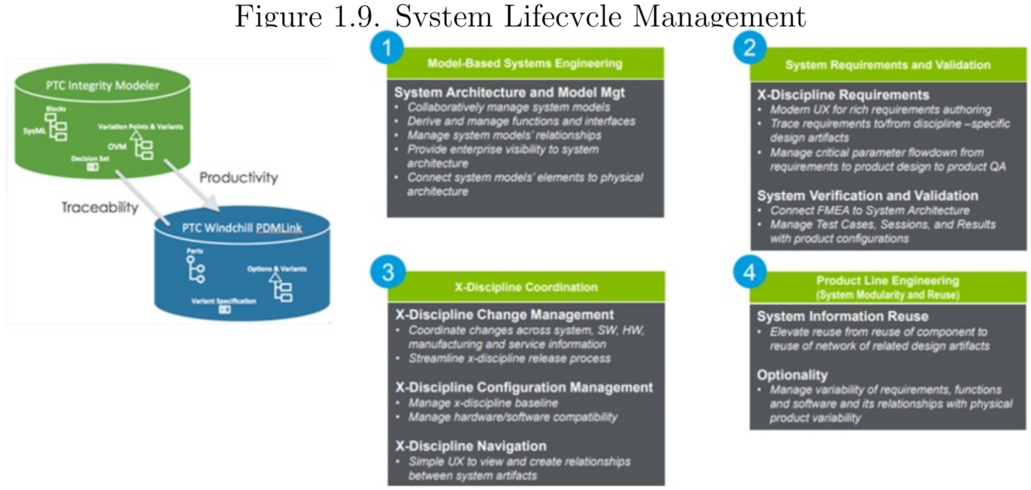


Figure 1.10. Approach by PTC

entire product lifecycle, MBSE captures and communicates system requirements and architecture using visual models and standards-based notation to describe complex products and systems. Taking advantage of productivity data transfer between MBSE and PLM systems can deliver numerous benefits in product and process development activities.

Embedded Market Forecasters, a premier market intelligence and advisory firm in the embedded technology industry had conducted a survey in 2013. This survey was conducted to learn the effects of SE (System Engineering), MBSE (Model Based

System Engineering) and MBPLE (Model Based Product Line Engineering, MBSE-PLM) on development cost per project and on time delivery. The results of this survey

Figure 1.11. Survey

clearly show when used SE 59% projects were delivered on time. 62% when MBSE is used and 75% when MBPLE used. Also, MBSE takes 55% reduction in Total Development Cost per project and MBPLE takes 62% reduction when compared to SE. [15]

4. Also, according to the latest report of the International Council on systems Engineering (INCOSE), model based systems engineering was very likely to replace the document-centric approach practised by most systems engineers. By 2011 SysML was used by 20% of aircraft and defence companies and 7% of automotive manufactures [16]. The figure below provides an overview of the main differences between a document-based verification and a model-based one. The documents that are produced in the traditional process, reported in (a), could be replaced by a system model which is able to include system requirements, the specification of validation and verification, and of their activities (e.g. test or analysis), which is linked with test and analysis models (including flight units), related results and reports, as outlined in (b). If documents are still required, they could be generated from these models. Our research scope drives on the same lines but our idea is to make it more approachable and better by integrating an PLM information system tool which brings in benefits such as automatic generation of system requirements documents. Therefore, extending a traditional PLM framework through adoption of Systems Engineering and Model-Based Systems Engineering methodologies multiplies its typical benefits.

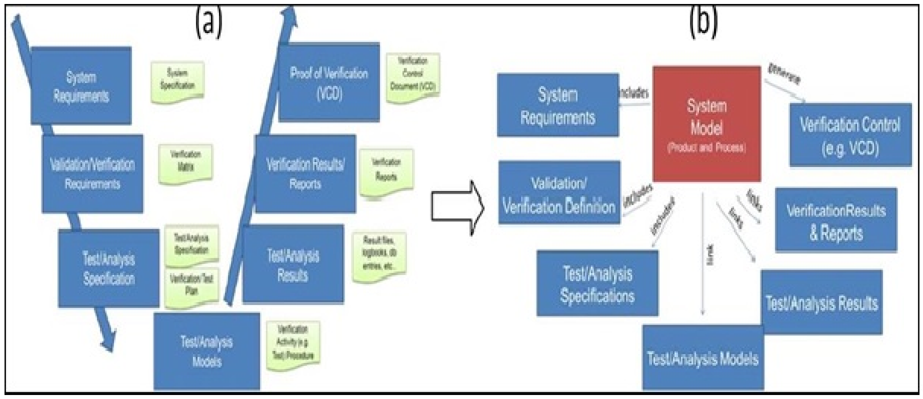
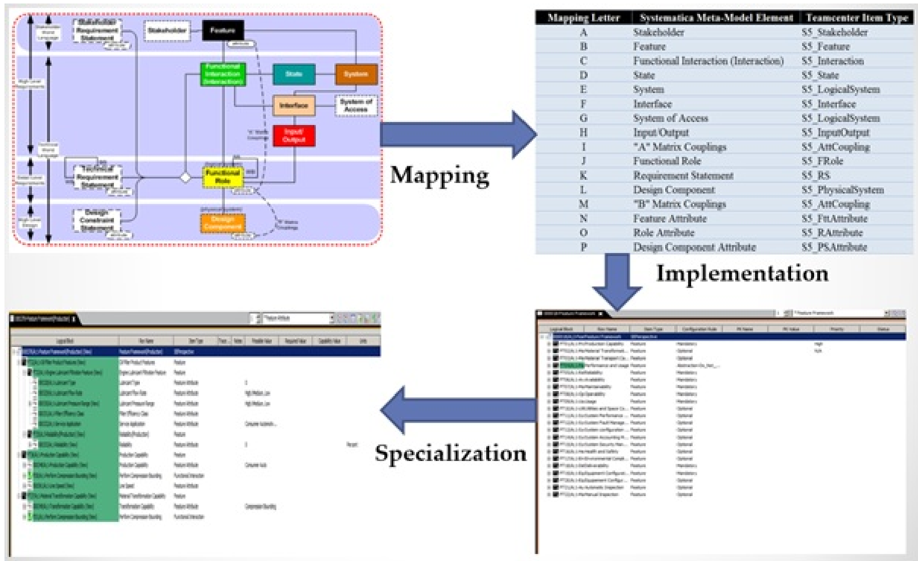


Figure 1.12. Verification Process: from Document Based to Model Based

The introduction of Model-Based (MBSE) data structures opens the door for integration of a wide range of model-oriented tools, integrated by a common fabric. But, merely using PLM information technology does not guarantee of MBSE model coverage, unless managed. In this study we introduce the integration of Pattern-Based System Engineering (PBSE) into a Product Lifecyle Management (PLM) platform. Introduction of pattern-based data structures opens door for machine-assisted platform and product line management. A common federated conceptual reference model (S*Metamodel) further enables this vision.

1.3 Thesis Outline



Mapping Letter	Systematica Meta-Model Element	Teamcenter Item Type
A	Stakeholder	S5_Stakeholder
B	Feature	S5_Feature
C	Functional Interaction (Interaction)	S5_Interaction
D	State	S5_State
E	System	S5_LogicalSystem
F	Interface	S5_Interface
G	System of Access	S5_LogicalSystem
H	Input/Output	S5_InputOutput
I	"A" Matrix Couplings	S5_AttCoupling
J	Functional Role	S5_FRole
K	Requirement Statement	S5_RS
L	Design Component	S5_PhysicalSystem
M	"B" Matrix Couplings	S5_AttCoupling
N	Feature Attribute	S5_FttAttribute
O	Role Attribute	S5_RAttribute
P	Design Component Attribute	S5_PSAttribute

Figure 1.13. Previous work: Research Approach

In our previous work the above research approach was used to build some of the components of metamodel in the aim for integration of PBSE and PLM. A generic model of S*Metamodel was created in Teamcenter. The mapping process provided the General Production Pattern and oil filter specialization model with fundamental capabilities. The approach defined above is to map the S*Metamodel in Teamcenter using Business Modeler IDE and implementation is done by creating custom oriented business objects in BMIDE and later using the generic model for specialization of the use case, i.e.: Oil filter. This work included the mapping of specific only few of the blocks of the Metamodel. [17] In the current work, S*Metamodel has been fully implemented to configure a PLM platform (TEAMCENTER) which supports automatic generation of reports and requirements tables using a generic Oil Filter system lifecycle.

There are three tables that have been configured for automatic generation which are Feature definitions table, Detail Requirements table and Stakeholder Feature Attributes table. These tables where specifically chosen as they describe all the requirements of the system and cover all the physical behaviours the oil filter system shall

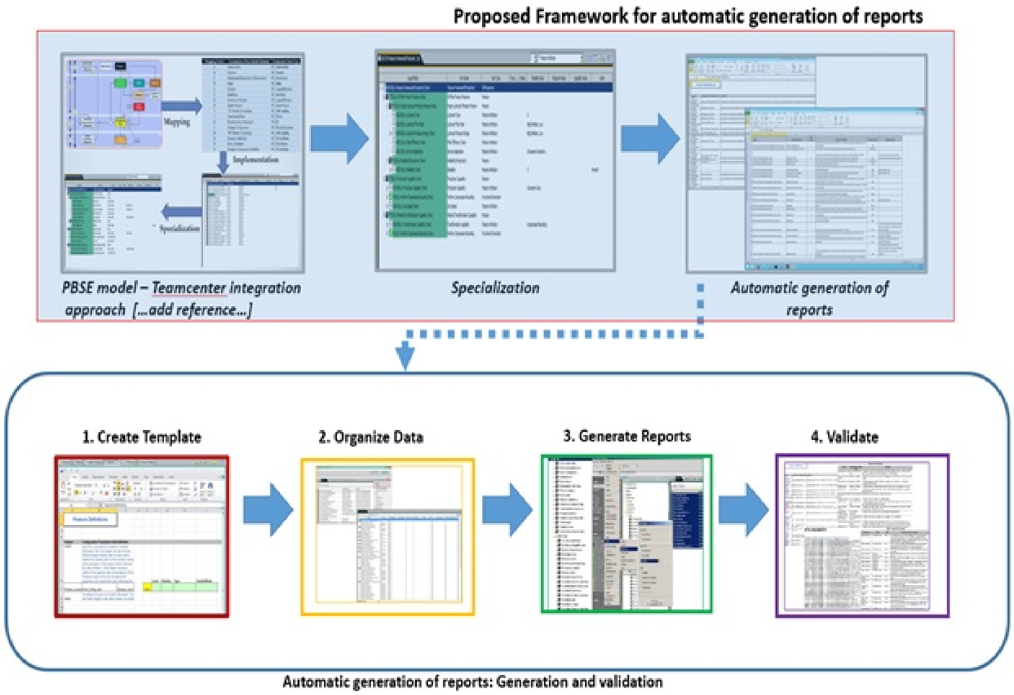


Figure 1.14. Current Approach

exhibit during its physical interactions with external systems. The tables and the diagram are core content for a typical systems engineering report. With the help of the automatic report generation tool, it is possible to prepare the entire report within one single system, the PLM system, to ensure a single reliable data source for an organization. Automatic generation of these contents can save the systems engineers time, avoid duplicated work and human errors in report preparation, and encourage standardized documents in an organization This model is used to generate Automatic System requirements documents and validate this integration by comparing the generated documents with document created by a professional systems engineer.

2. METHODOLOGY AND IMPLEMENTATION

2.1 Pattern Based System Engineering

Pattern recognition and classification have a mathematical theory and engineering practices. [18].Patterns in engineered systems were recognized in building architecture, later inspiring software engineers, and more recently systems engineers. [19] [20] [21] [22]. Patterns were traditionally represented by templates which then merged with MBSE leading to Pattern based system engineering. [23] [22]

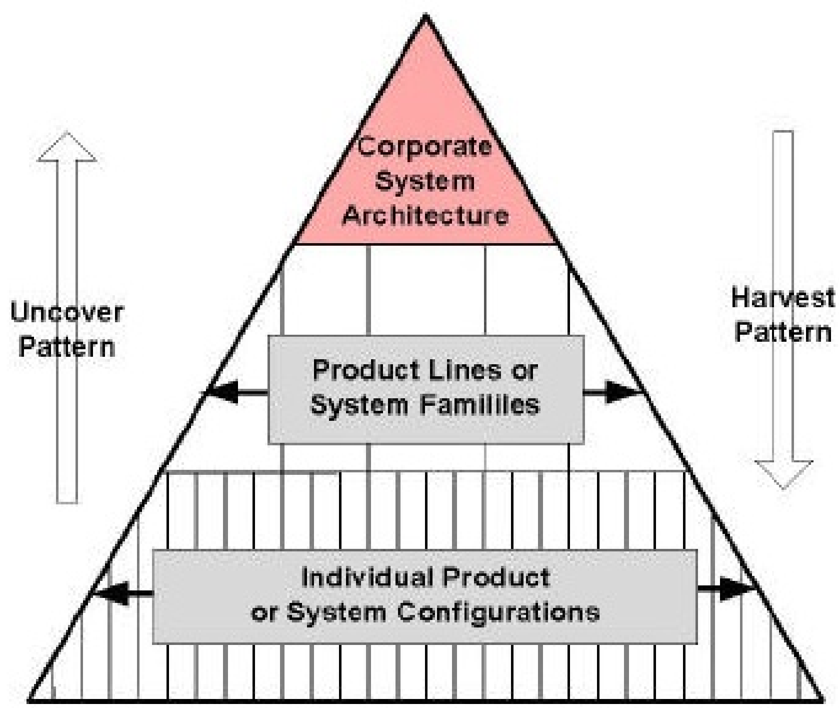


Figure 2.1. PBSE Pattern Pyramid

Pattern class hierarchy:

The pyramid consisting the meta-model represents a system or product by layers. The pyramid start with inclusion of the entire model in the top layer described by the meta-model which considers important features such as requirements and design of all the product lines. The middle layer covers the configurations which are similar enough to be connected to the same system and finally the bottom layer consists of specific requirements and design models and therefore derived specifications are followed to build the product lines or system. [24]

There are two important aspects of the pyramid which are represented on the either sides:

Uncovering Patterns and Harvesting patterns represent the future of the systems where the product can be recognized,developed from scratch and then can be brought into the existing product lines or systems and thereby creating new market value and increasing revenue.

The main advantage of patterns is that they are re-usable and reconfigurable models. The reusability is possible because of reusable requirements for one true family of products, and hence the products can be reconfigured accordingly. Reusable requirements are some common needs across different applications, product lines or subsystems. To create a perfect modelling framework parametrized requirements statements are glued to overall requirements of the systems which inherently enables Pattern-based System Engineering.

2.1.1 S*Metamodel

It provides an underlying framework that defies the semantic meaning of models conforming to it. Pursued over a number of years and tests, the contempory system models are often both semantically too big (redundant) and too small (missing important information), at the same time. [25]. This study utilizes the S* Metamodel, a relational/object information model used in Systematica methodology to describe requirements, designs, and other (verification, failure analysis, etc.) information. This metamodel has been applied to systems engineering in mil/aero, transportation, communication, medical and health care, consumer products, construction, manufacturing, and as a framework for educating new engineers. [26] [27] [23] [28] [22] [29].

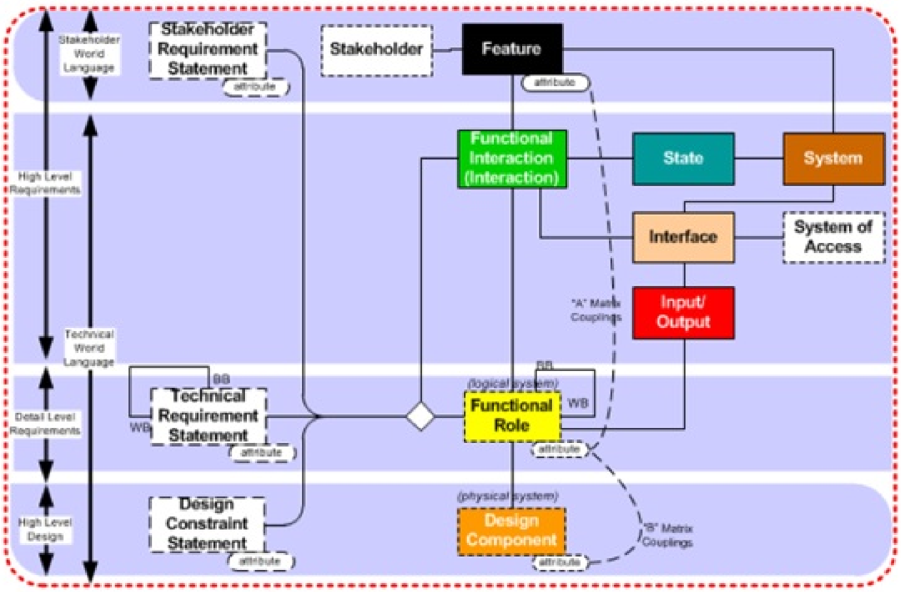


Figure 2.2. S*Metamodel=Smallest Model Necessary for Purpose of Science, Engineerig, Life Cycle Management

Each Block of the figure 2.2 is defined below and relationships as they are connected with:

Stakeholder is an entity having a value stake in the behaviour or performance of the system.

Feature shows the performance of a system that has stakeholder value, described in the concepts and terminology of that stakeholder, and serving as the bases of selection of systems or system capabilities by or on behalf of the stakeholder. Features are parameterized by Feature attributes, which have subjective stakeholder valuations.

Functional Interaction means the exchange of information between system components, each of which plays a Functional Role in that interaction.

Functional Role means the behavioural description (and therefore a logical system) of a part played by a system in a functional interactions relationship.

The **state** of a system determines what behaviour it will exhibit in future interactions. The state of a system may be changes by those interactions.

Input/output is that information which is externally exchanged between interacting systems.

Interface is the association of a system with a set of its Functional Interactions(s), Input/output(s), Architectural Relationship(s), and System(s) of Access.

Design Component is a physical system that is within a subject systems physical system containment hierarchy and to which is allocated functional roles.

Requirements Statements are the descriptions equivalent to the roles they describe, and are measured by Requirements Attributes which are identical to the related Role Attributes.

Matrix A couplings describe the quantitative value dependencies (parametric couplings) between Stakeholder Feature Attributes and Functional Role Attributes, quantifying fitness space or trade space.

Matrix B couplings describe the quantitative value dependencies (parametric couplings) between Functional Role Attributes and Physical Design Component Attributes **Logical System** is a system identified solely by its externally viewable behavior or responsibility.

System Interactions represents interactions between physical systems with views from science.

It is important to indentify interactions while building a model, S*Metamodel is built on the foundations of system interactions. [30]). Identifying these interactions is not only done by modelling tools but tolerated by them. System Failures for human engineered systems have purpose, analysis of failure modes and effects (FMEA, FMECA, etc.) and other forms of risk analysis are central to systems engineering and are likewise fundamental to the S*Space described by the S*Metamodel. [31]. Requirements are the most important aspect of a system engineer. Significant study is done to covert these textual gestures to more easy to understand methodology such as models. However, these text representations are the prose equations of the non-linear extension of transfer functions [32], even if not recognized as such. Accordingly, the related transfer function abstraction is fundamental to the S*Metamodels integration of requirements.

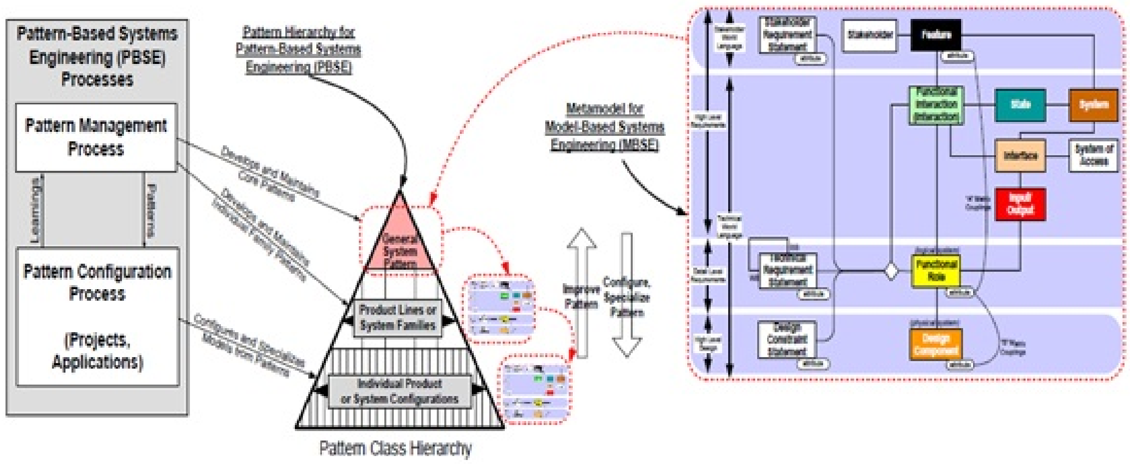


Figure 2.3. S* Models which are Reusable

S*Patterns are S*Models (with all their parts) that have been constructed to cover a system configuration space bigger than single system instances, and are sufficiently parameterized and abstracted to be configurable to more specific S*Models, and thereby reusable, as in Figure [23] [32] [27] [5]

The above figure illustrates the process by which patterns of requirements and design for generic systems can then be configured or specialized into individual product line families, and ultimately individual product systems. This approach has been applied in a number of Commercial off the shelf (COTS) product line enterprises, to enhance COTS portfolio engineering and planning. This approach also facilitates the ongoing expression of organizational learning in the form of updates and refinements to uncovered patterns. A particularly Striking benefit of this approach is that it allows large organizational practitioners who are less skilled in clean sheet original modelling to gain benefits of model-based engineering.

2.2 Teamcenter

It is a PLM solution initially developed by UGS Corporation, a company which later became Siemens PLM Software which has made it the most widely used PLM platform in the world.

Various modules in Teamcenter include:

Portfolio, program and project management: This module uses Microsoft office to align with the PLM workspace thereby increasing productivity.

Compliance management: Mitigate risks of non-compliance by identifying managerial activity.

Systems engineering and requirements management: This module is used to alleviate new risk created while implementing a new product in the system.

Engineering process management: One single repository for design workforce.

Bill of materials management: Deliver quality product and right time along with product verification.

Content and document management: Improve productivity by leveraging SGML/XML to rapidly publish multiple product variant documents.

There are many other modules which are not in the current cope of this study. We use the systems engineering and requirements management module, Bill of materials management module and the content and document management modules in this study. S* Metamodel has been implemented in the systems engineering and requirements management module. Content and document management module is used to organize data and then integration with MS word allows us to create requirements document.

2.2.1 System Engineering (SE) and Product Lifecycle Management (PLM)

The common factor between SE and PLM is Product (or System).SE is focused on the specification of the system (architecture) and its performance against the stakeholders requirements. On the other hand, PLM handles the integrated and coordinated development, maintenance and use of all product (or system) data and relevant engineering information throughout the entire product lifecycle.

The idea is to enable Systems Engineering with the information and process management capabilities of PLM solutions. This idea when implemented will be a holistic approach to develop, deliver and support optimum product solutions. At its core, it defines and associates requirements to functions, functions to logical representations, and logical representations to physical designsproviding an architectural framework for the downstream physical implementation of all the systems associated with the product, including manufacturing, support, and ultimately recycling.

2.2.2 Teamcenter as a System Engineering Driven PLM Tool

This module helps system engineers to make better decisions by providing continuous feedback and all the while realizing the criticality of the risk involved.

Extended application and systems integration: This feature defines the interconnectivity Teamcenter provides by liking different softwares with live integration into PLM workspace.

Requirements traceability: System Engineers are always looking to integrate requirements to lower-levels to provide enough understanding on why a requirement is determined and how it is inclined to higher level stakeholder needs. System Engineers can use this feature in Teamcenter for traceability to track and manage requirements.

Requirements management: This feature in Teamcenter is used to implement all the stakeholders needs and identify requirements. Requirements here can be managed, extracted and linked for extensive use.

There are many other features of Teamcenter but are out of scope for this study. Above mentioned are the main functionalities used extensively in this study.

Current Teamcenter SE Functionality include:

- **To Develop and manage requirement structures**

- **To Develop functional model structure using structure manager**
- **To Create and maintain logical model structures**
- **To Relate requirements and structure components with trace links**
- **To Create and maintain physical model structures**
- **To Manage changes, change requests, performing impact analysis**
- **To Perform simulation and model the behavior of model components**

Teamcenter modules involved with SE include System Engineering, Requirements Manager, Structure Manager, Multi-Structure Manager, Change Manager, Manufacturing Process Planner, and Workflow Manager. Teamcenter Systems Engineering represents a highly integrated PLM-enabled solution. CIMdatas research and experience indicate that the potential payoffs for companies that utilize such an integrated approach can be significant. This integration helps in reducing hidden risks, in the absence of sound enterprise information asset strategies, information and valuable insights can be lost which has a direct impact imposing huge costs on future products because of poor decision making, repeated mistakes and lessons learned that are not passed on.

2.2.3 BMIDE(Business Modler Integrated Developing Environment)

The Business Modeler IDE (Integrated Development Environment) is a tool for configuring and extending the data model of your Teamcenter installation. The data model objects define the objects and rules used in Teamcenter. BMIDE is used to

1. Create new data model elements
2. Perform C++ customizations
3. Migrate data using the mapping designer

Business objects are the fundamental objects used to model business data. Business objects were formerly known as types in Engineering Process Management. One of the most important jobs you perform in the Business Modeler IDE is to create business objects to represent different kinds of parts, documents, change processes, and so on. The Business Modeler IDE is a tool for adding your own data model objects on top of the default Teamcenter data model objects. The Business Modeler IDE accomplishes this by separating your data model into its own set of files that are kept apart from the standard data model, known as the COTS (commercial off-the-shelf) data model.

There are several ways to do customization some of the important are:

Data-model-based customization Allows Addition of custom C++ operations to business objects, and the overriding of existing operations on business objects.

Teamcenter Services customization Allows custom service-oriented architecture (SOA) service operations and the low level data model objects. These are less granular services that improve the performance of client communication in a Wide-Area-Network (WAN) environment.

Extensions customizations Allows you to write a custom function or method for Teamcenter in C or C++ and attach the rules to predefined hook points in Teamcenter (preconditions, pre-actions, and post-actions). Also, existing operations can be extended to these hook points.

Few of the various capabilities of BMIDE are:

1. The BMIDE manages all extensions through a template.

2. Business Analysts create an Extension Environment Project in the BMIDE that manages a customer template.

3. As Types, Classes, Attributes, LOVs, etc are created in the BMIDE that are automatically placed into the template.

4. The template becomes the mechanism for deploying custom extensions to any Teamcenter environment.

5. Customers desiring to tailor Teamcenter business behaviour can start with a new clean template.

2.2.4 Methodology to Create Business Objects

Business objects are fundamental objects used to model business data. Business objects are created to represent product parts, documents, change process, and so on.

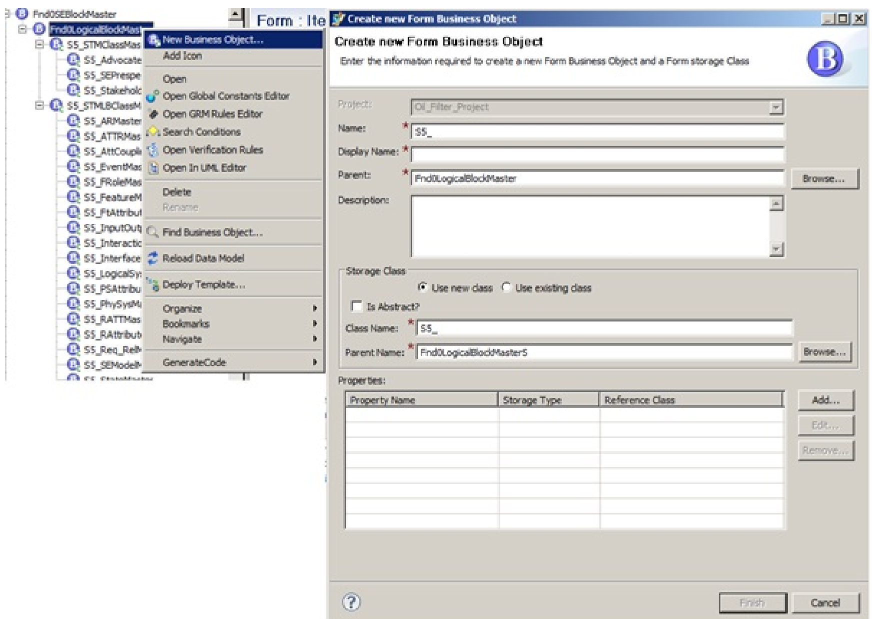


Figure 2.4. How to Create Business Objects in BMIDE

The above figure depicts the user interface on BMIDE and shows the steps involved in creating a business object. It is very important to select a parent object and it subsequently created a business class which later can be customised with properties, List of Values (LOVs) etc.

Implementation to Create Custom Oriented Business Objects:

We received mapping document from our stakeholders (ICTT system Sciences). This document describes the various classes describing all the blocks of the S*Metamodel.

Specialized Item Type	Item Type Superclass	Teamcenter Base Item Type
S5_STMLBClass	Fnd0LogicalBlock	Item
S5_STMClass	Fnd0LogicalBlock	Item
S5_STMRSClass	Requirement	Item
S5_IsSourceOf	FND_Tracelink	Trace Link
S5_IsSuperclassOf	FND_Tracelink	Trace Link
S5_SEModel	S5_STMLBClass	Fnd0LogicalBlock
S5_Feature	S5_STMLBClass	Fnd0LogicalBlock
S5_FtAttribute	S5_STMLBClass	Fnd0LogicalBlock
S5_LogicalSystem	S5_STMLBClass	Fnd0LogicalBlock
S5_Interface	S5_STMLBClass	Fnd0LogicalBlock
S5_AR	S5_STMLBClass	Fnd0LogicalBlock
S5_InputOutput	S5_STMLBClass	Fnd0LogicalBlock
S5_State	S5_STMLBClass	Fnd0LogicalBlock
S5_Event	S5_STMLBClass	Fnd0LogicalBlock
S5_Interaction	S5_STMLBClass	Fnd0LogicalBlock
S5_FRole	S5_STMLBClass	Fnd0LogicalBlock
S5_RATT	S5_STMLBClass	Fnd0LogicalBlock
S5_RAttribute	S5_STMLBClass	Fnd0LogicalBlock
S5_AttCoupling	S5_STMLBClass	Fnd0LogicalBlock
S5_PhysicalSystem	S5_STMLBClass	Fnd0LogicalBlock
S5_PSAttribute	S5_STMLBClass	Fnd0LogicalBlock
S5_Req_Rel	S5_STMLBClass	Fnd0LogicalBlock
S5_ATTR	S5_STMLBClass	Fnd0LogicalBlock
S5_SEPrespective	S5_STMClass	Fnd0LogicalBlock
S5_Stakeholder	S5_STMClass	Fnd0LogicalBlock
S5_Advocate	S5_STMClass	Fnd0LogicalBlock
S5_Need	S5_STMRSClass	Requirement
S5_RS	S5_STMRSClass	Requirement

Figure 2.5. Detailed Class Type for S*Metamodel for Input in BMIDE (credit:ICTT System Sciences)

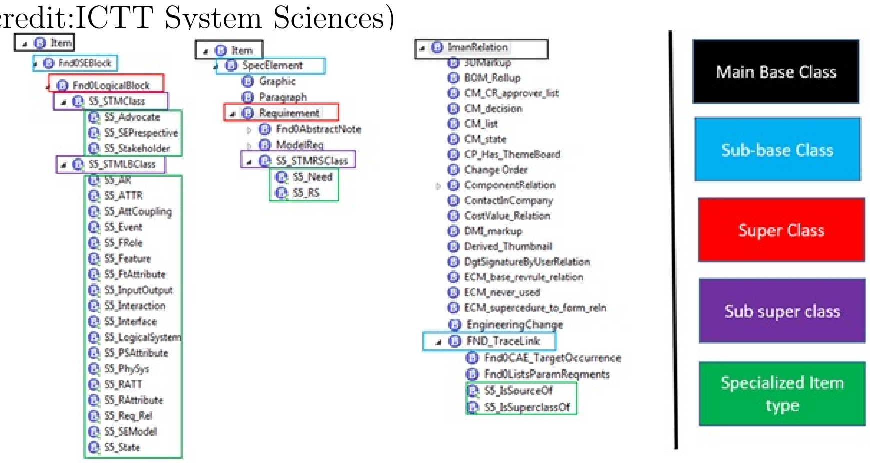


Figure 2.6. List of all Classes Created in BMIDE for the S*METAMODEL

The figure 3.6 clearly represents all metaclasses that represent the S*Metamodel created in BMIDE. The figure also distinguishes the Main Base Class, Sub-base Clas, Super Class, Sub super class and Specialized Item type.

2.2.5 Methodology to Assign Properties to Business Objects

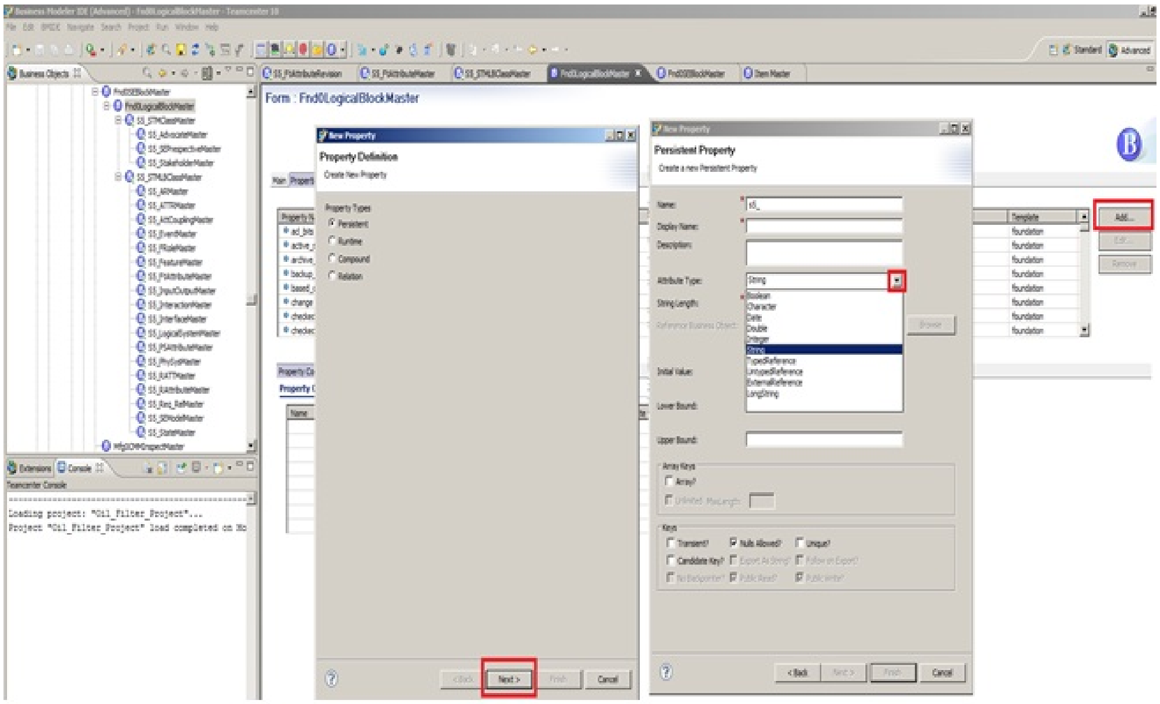


Figure 2.7. How to Create Properties in BMIDE

To add properties in we first select the business object and then add custom properties from property types such as persistent, Runtime, Compound and relation. The figure uses persistent property as an example where attribute types can be Character (Such as A, B, Z), Date (Calendar Date), Double (floating point decimal number), Integer (1 to 999999999), String (string of characters), Typed Reference (points to a Teamcenter class), Untyped Reference (points to any class of data), External Reference (points to data outside of Teamcenter), and Long String (String of unlimited length).

Implementation to Create Custom Properties to Business Objects

By following the above methodology and the required input from 2.8 is used to assign custom properties to business objects.

A	B	C	D
Class	Properties	Properties Display Name	Attribute Type
S5_STMLBClassRevision	s5_Status	Status	String[32]
S5_FeatureRevision	s5_Config_rule	Configuration Rule	String[32]
S5_FeatureRevision	s5_FPK_Name	FPK Name	String[32]
S5_FeatureRevision	s5_FPK_Value	FPK Value	String[200]
S5_FeatureRevision	s5_Priority	Priority	String[32]
S5_FtAttributeRevision	s5_Capability_Vaule	Capability Vaule	String[200]
S5_FtAttributeRevision	s5_Possible_Value	Attribute Value	String[32]
S5_FtAttributeRevision	s5_Required_Value	Required Value	String[32]
S5_FtAttributeRevision	s5_Units	Attribute Units	String[32]
S5_FtAttributeRevision	s5_PK	PK	String[32]
S5_LogicalSystem	s5_Domain_Diagram	Domain Diagram	String[32]
S5_LogicalSystem	s5_Logical_Arch_Diagram	Logical Architectural Diagram	String[32]
S5_LogicalSystem	s5_RPK_Rule	RPK Rule	String[32]
S5_LogicalSystem	s5_LSValue	Logical Systems Value	String[32]
S5_Interaction	s5_IPK_Value	IPK Value	String[200]
S5_Interaction	s5_FPK_Value	FPK Value(Relationship)	String[200]
S5_Interaction	s5_IPK_Rule	IPK Rule	String[32]

Figure 2.8. Detailed List of Custom Properties for Input in BMIDE

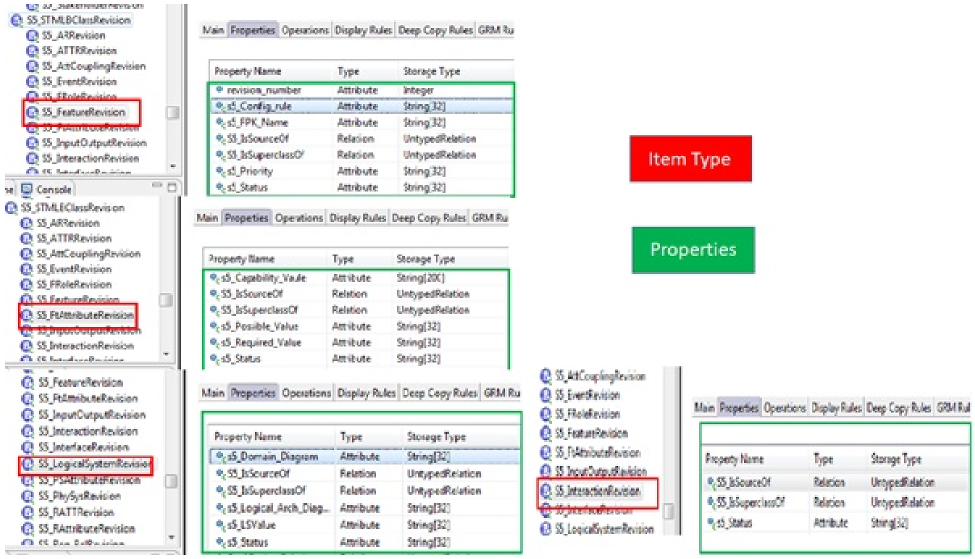


Figure 2.9. All Properties Defined for Custom Oriented Functionality

2.2.6 Methodology to Add Lists of Values (LOVs)

The LOV folder in the Extensions folder is used for working with lists of values (LOVs). LOVs are pick lists of data entry items.

There are three main types of lists of values:

1. **Batch**: Store LOV values in Teamcenter database rather than storing them in template.

2. **Classic**: Store the LOV values in the template.

3. **Dynamic**: Read the LOV values dynamically by querying the database.

After creating, it is important to attach the LOV to a property on a business object. We use Classic LOV in this study because Classic lists of values (LOVs store the LOV values in the template.

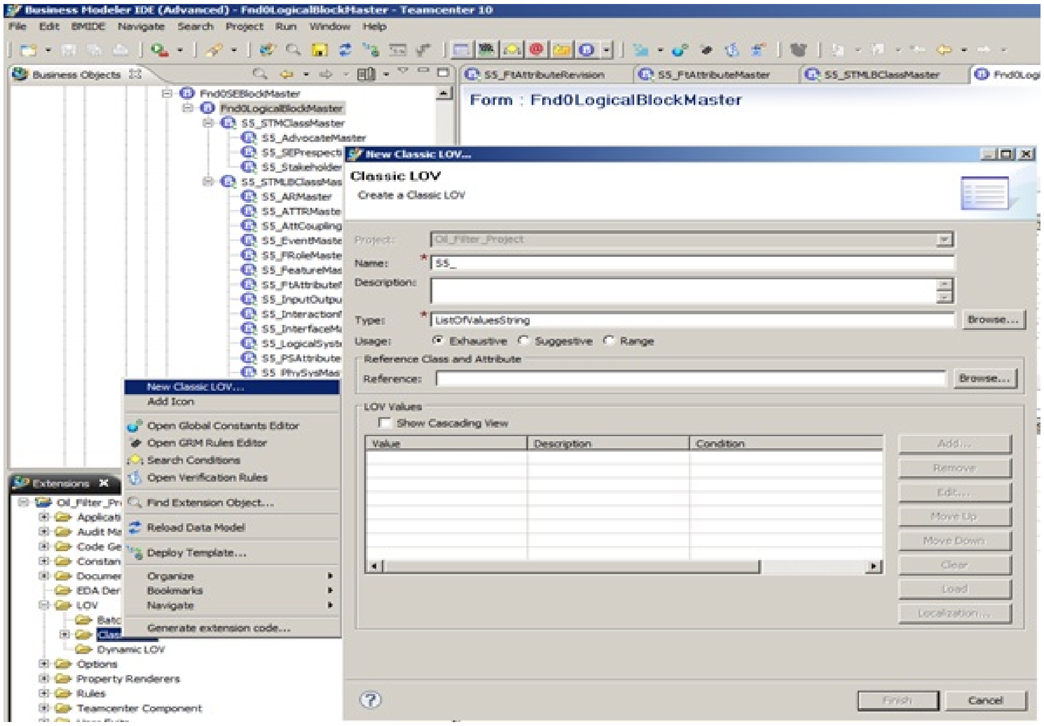


Figure 2.10. Method to Add Classic LOV to Custom Template

Implementation to Add Custom List of Values (LOVs)

The Figure 2.11 shows the information received from stakeholders in regards to the custom abilities of the model.

Class	Properties	Properties Display Name	Attribute Type	LOV
S5_STMLBClassRevision	s5_Status	Status	String[32]	S5_Status
S5_FeatureRevision	s5_Config_rule	Configuration Rule	String[32]	S5_ConfigRule
S5_FeatureRevision	s5_FPK_Name	FPK Name	String[32]	N/A
S5_FeatureRevision	s5_FPK_Value	FPK Value	String[200]	N/A
S5_FeatureRevision	s5_Priority	Priority	String[32]	S5_Priority
S5_FtAttributeRevision	s5_Capability_Vaule	Capability Vaule	String[200]	N/A
S5_FtAttributeRevision	s5_Possible_Value	Attribute Value	String[32]	N/A
S5_FtAttributeRevision	s5_Required_Value	Required Value	String[32]	N/A
S5_FtAttributeRevision	s5_Units	Attribute Units	String[32]	N/A
S5_FtAttributeRevision	s5_PK	PK	String[32]	N/A
S5_LogicalSystem	s5_Domain_Diagram	Domain Diagram	String[32]	S5_Domain_Diagram
S5_LogicalSystem	s5_Logical_Arch_Diagram	Logical Architectural Diagram	String[32]	S5_Logical_Arch_Diagram
S5_LogicalSystem	s5_RPK_Rule	RPK Rule	String[32]	N/A
S5_LogicalSystem	s5_LSValue	Logical Systems Value	String[32]	N/A
S5_Interaction	s5_IPK_Value	IPK Value	String[200]	N/A
S5_Interaction	s5_FPK_Value	FPK Value(Relationship)	String[200]	N/A
S5_Interaction	s5_IPK_Rule	IPK Rule	String[32]	N/A

Figure 2.11. Detailed Representation of the Custom LOV for Respective Classes

2.2.7 Methodology for Automatic Generation of Reports

To generate the reports automatically from Teamcenter the first step involved is to create an Excel template specific to the requirement.

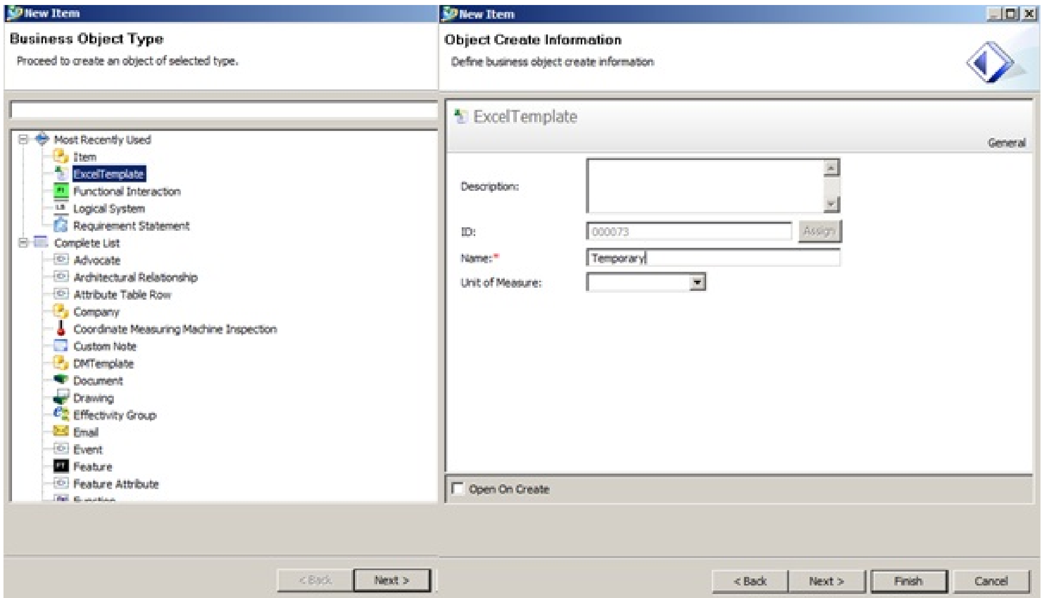


Figure 2.12. Method to Create an Excel Template

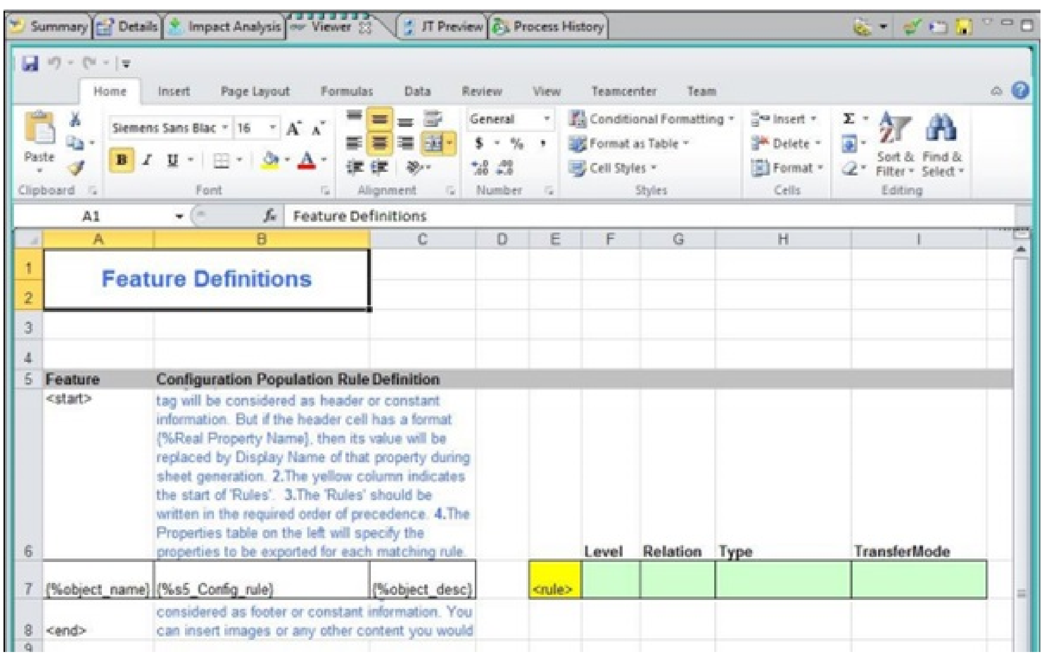


Figure 2.13. Figure Shows How to Customize a Excel Template

The above displays a window where the excel template can be customized according to the requirement. The next step is to build a series of Items and provide required description and custom properties. After you build a series of Items then you can either select all or send-to structure manager where we can further customize the product structure and add/remove content to display. Structure Manager is an application in Teamcenter that enables creation of generic product structures that can be configured to show the product structure that is in production, effective on a certain date, used by a particular customer, and so forth. Structure Manager enables creation and modification of a product structure and its associated occurrence data, display of a product structure in a multilevel indented format, and viewing graphics tightly coupled to the structure for easy identification of a component by location in the structure or in the embedded viewer. Structure manager displays your product structure in a multilevel indented list format, making it easy to browse. This list is similar to the bill of materials (BOM) that engineering organizations use to list manufacturing information.

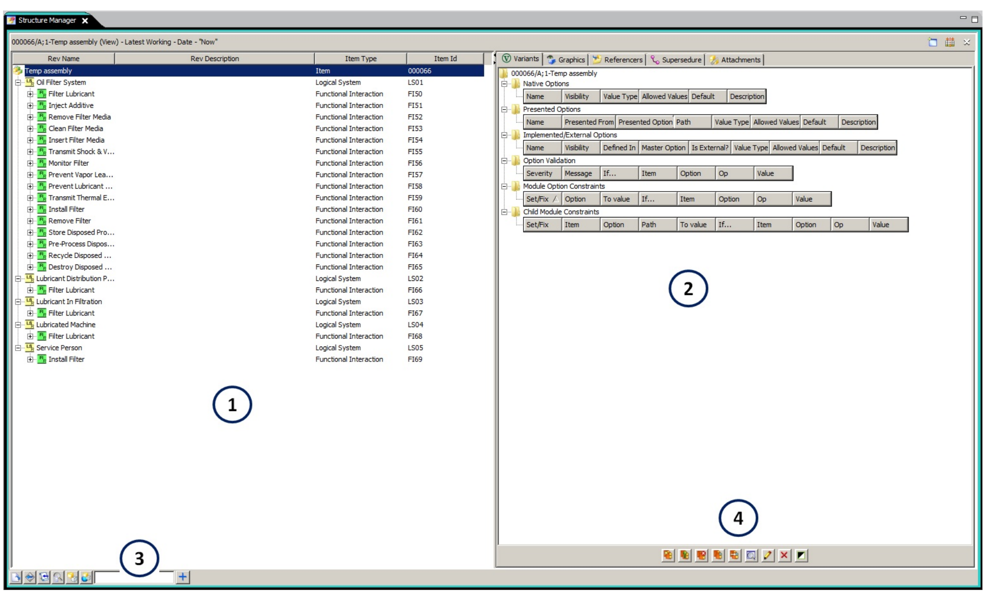


Figure 2.14. Structure Manager User Interface

1. **Structure navigation tree:** Allows you to navigate the product structure, expanding or collapsing nodes to view the appropriate data. The images in the tree indicate the purpose of each node.

2. **Data panes:** Allow you to view data about the selected line. To display a different data pane, click its tab.

3. **Search area:** Allows you to search for a structure and configure it with commonly used data.

4. **Incremental change management area:** Shows the current incremental change (if one is applied) and allows you to manage the incremental change data.

5. **Status symbols:** show the current status of the selected line.

The final step is to export files to excel to generate required reports.

The dialog box 2.15 gives you varied options to display output in excel.

1. Static snapshot: Generates a standard Microsoft Excel document that does not have Teamcenter live Excel capability.

2. Live integration with Excel (Interactive): Generates an Excel document with Teamcenter live excel capability, which means this integration is interactive therefore changes made in excel shall reflect in Teamcenter and vice versa.

3. Live integration with Excel (Bulk Mode): Generates Excel file that is not connected with Teamcenter but you can accumulate changes and later connect the file.

4. Work Offline and Import: To export the data to excel file that also contains import processing information on a separate sheet.

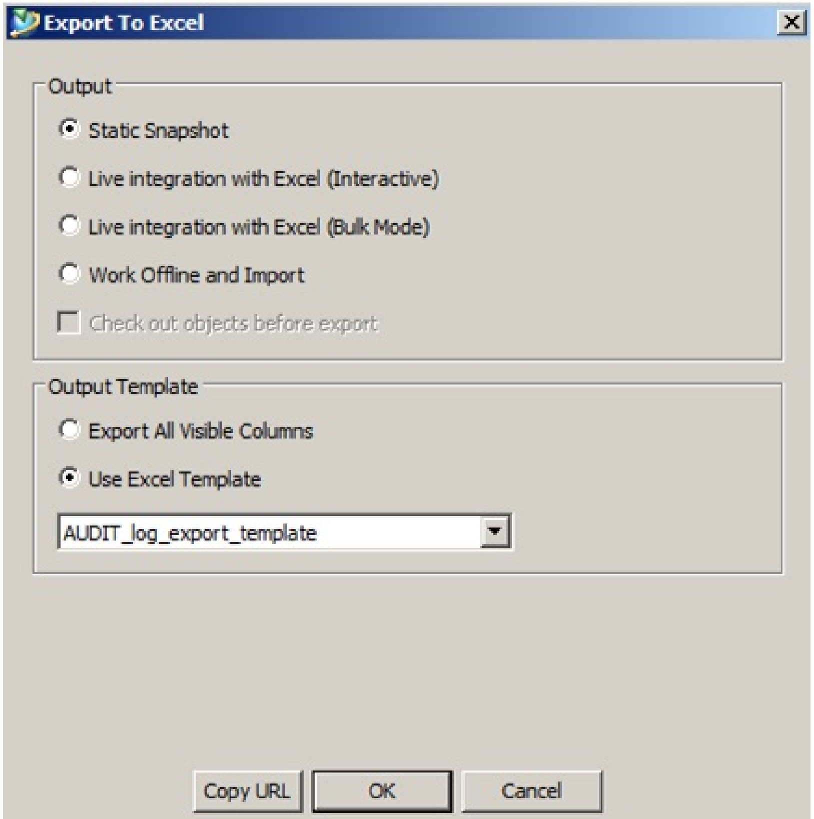


Figure 2.15. Export to Excel

Implementation to create custom reports:

Table 1: [Features Definitions Table] Stakeholder Features are formal statements of stakeholder requirements in the language and concepts of those stakeholders. As such, they are not necessarily objective or technically quantified in all cases, but nevertheless describe what must be accomplished in the minds of those for whom it must be accomplished. To generate this table an excel template was created as shown in the figure below

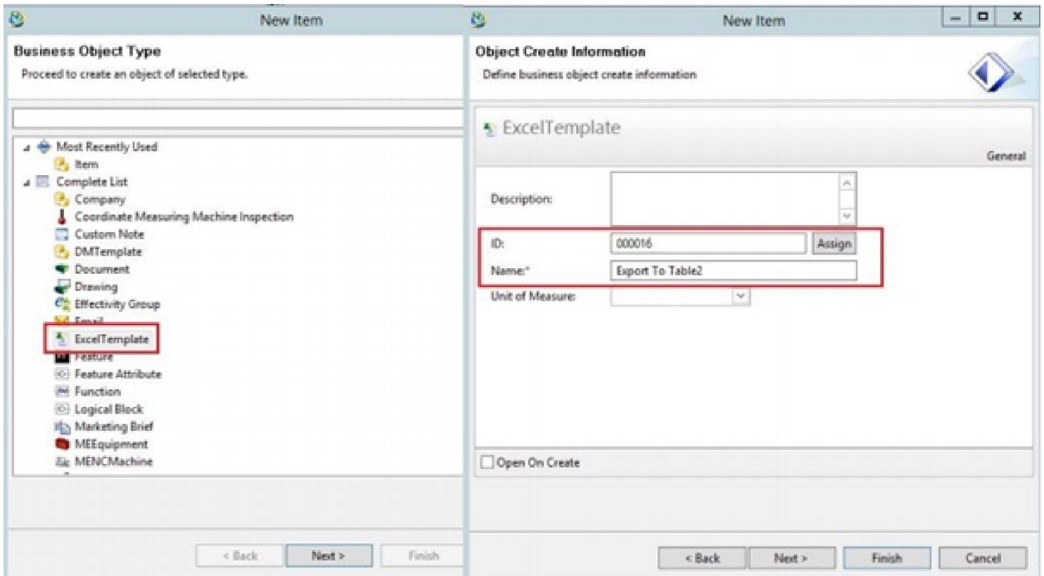


Figure 2.16. Create an Custom Excel Template

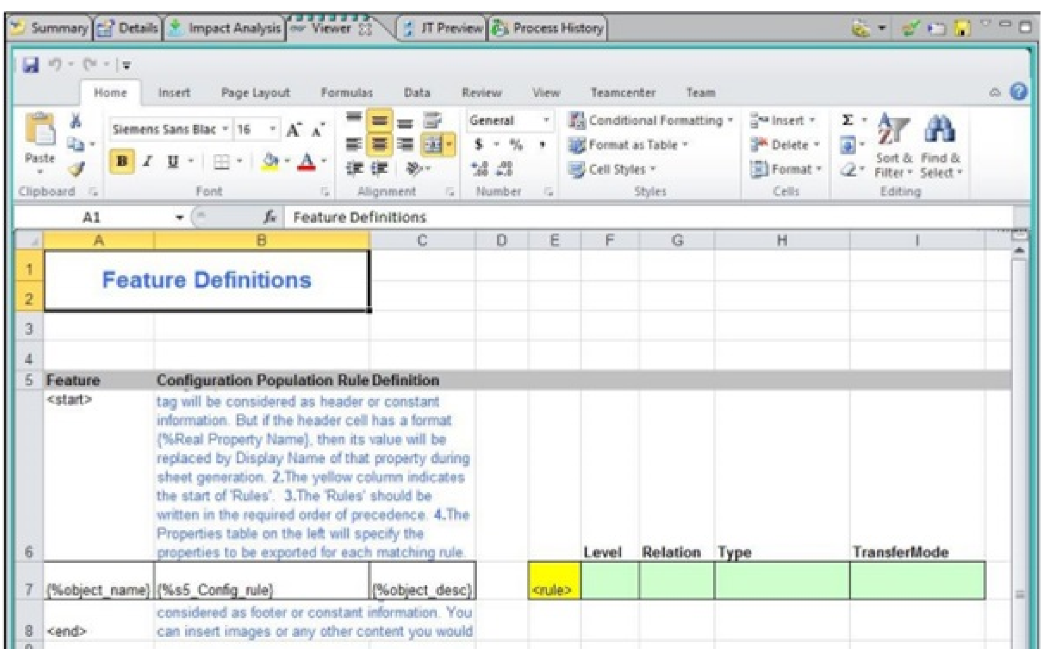


Figure 2.17. Define Custom Properties in Excel

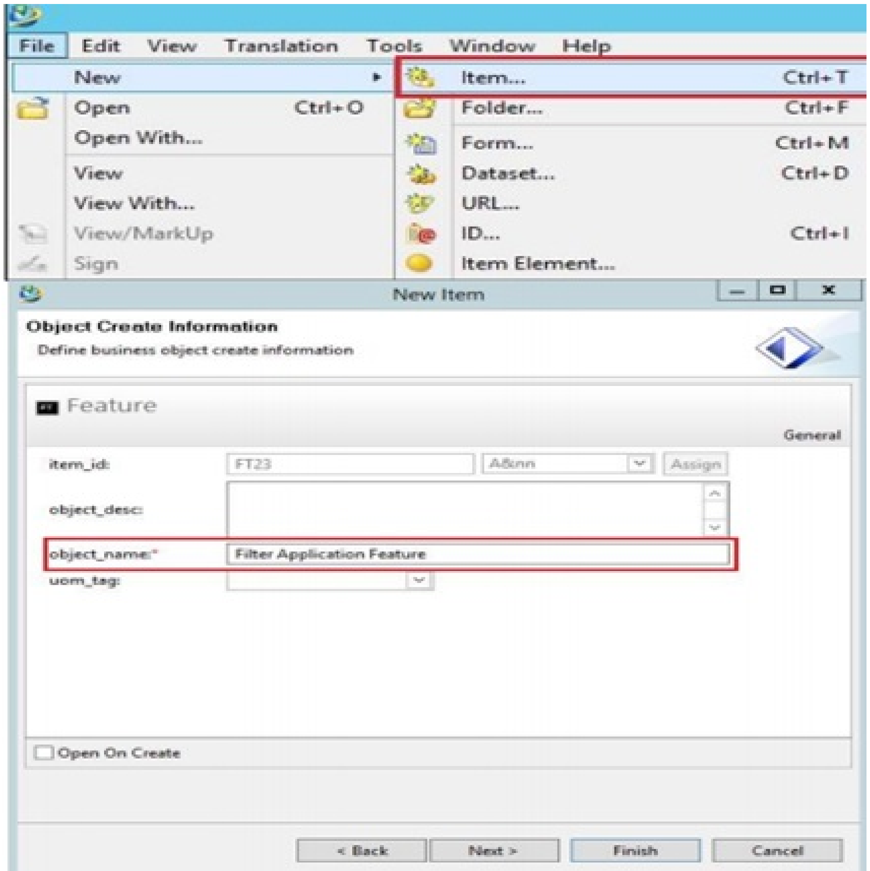


Figure 2.18. Create Custom Items and Enter Relevant Feature Name

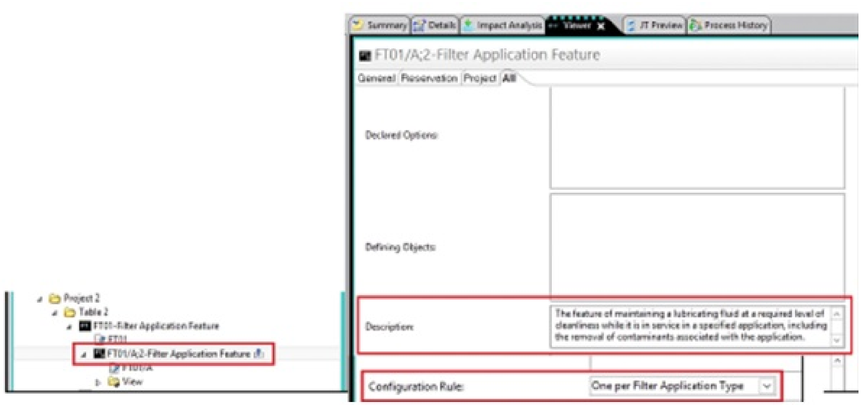


Figure 2.19. Fill Relevant Description

Repeat the above procedure for all custom items. The Figure 2.20 represents all the features created in Teamcenter in regards to the custom properties defined by the stakeholder.

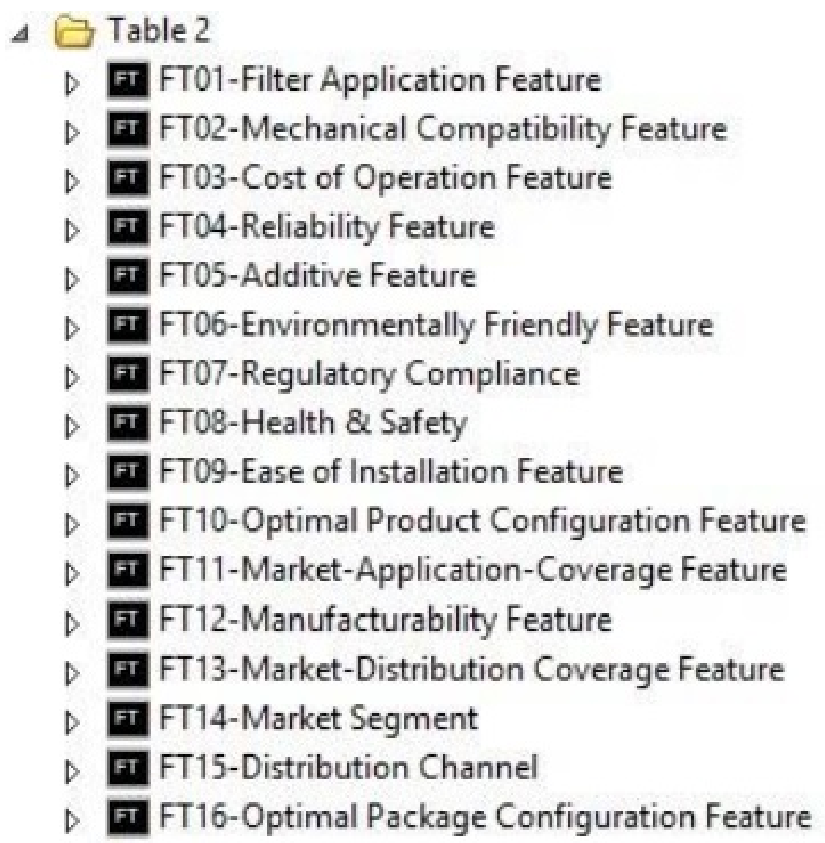


Figure 2.20. List of all Feature Items

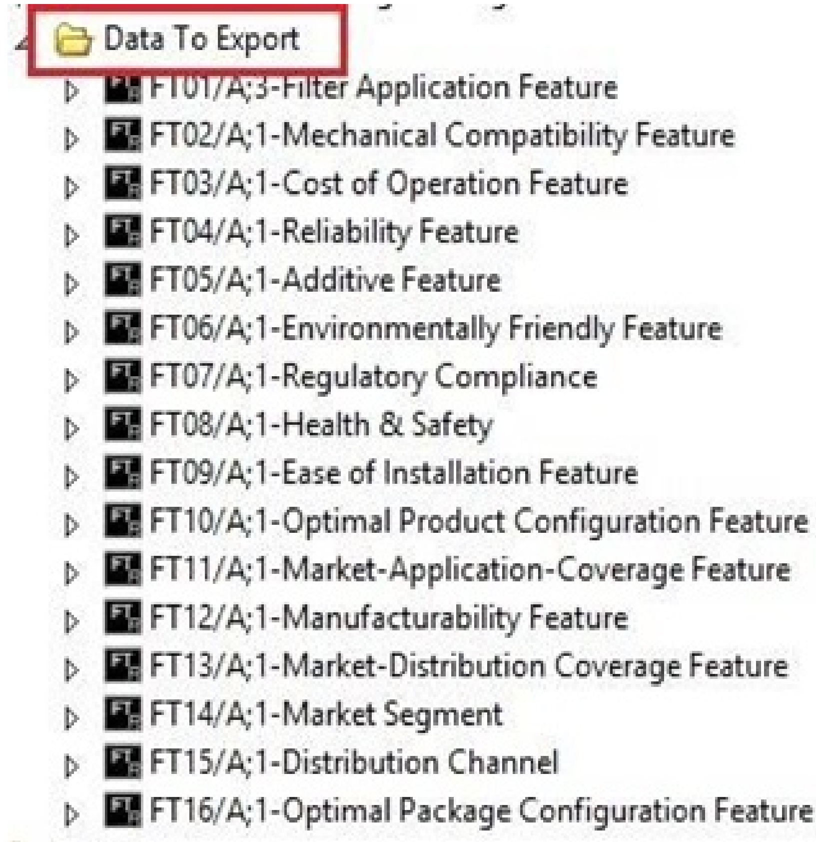


Figure 2.21. Create a New Folder for Export

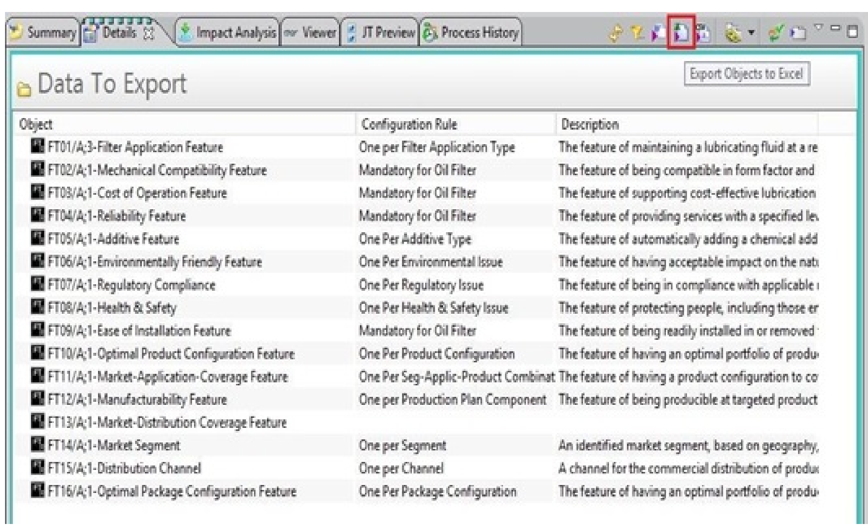


Figure 2.22. Feature Table Export to Excel

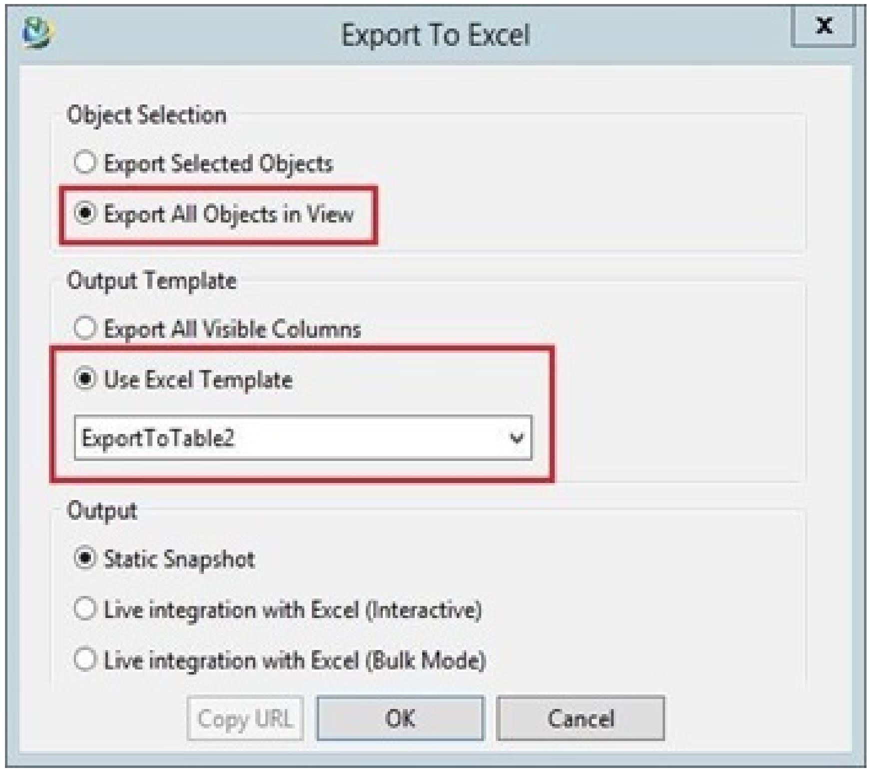
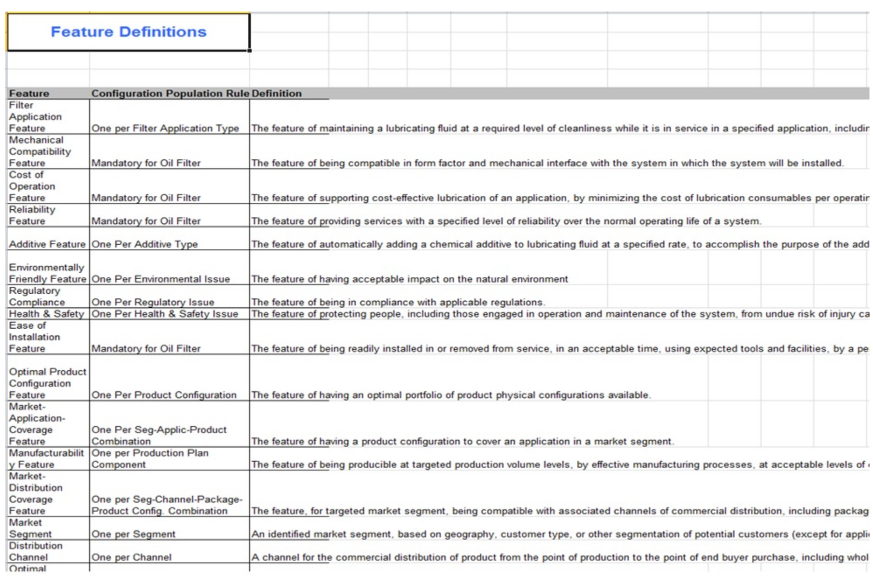


Figure 2.23. Export all Objects in View and Choose Custom Template



Feature Definitions

Feature	Configuration Population Rule	Definition
Filter Application Feature	One per Filter Application Type	The feature of maintaining a lubricating fluid at a required level of cleanliness while it is in service in a specified application, includir
Mechanical Compatibility Feature	Mandatory for Oil Filter	The feature of being compatible in form factor and mechanical interface with the system in which the system will be installed.
Cost of Operation Feature	Mandatory for Oil Filter	The feature of supporting cost-effective lubrication of an application, by minimizing the cost of lubrication consumables per operatir
Reliability Feature	Mandatory for Oil Filter	The feature of providing services with a specified level of reliability over the normal operating life of a system.
Additive Feature	One Per Additive Type	The feature of automatically adding a chemical additive to lubricating fluid at a specified rate, to accomplish the purpose of the add
Environmentally Friendly Feature	One Per Environmental Issue	The feature of having acceptable impact on the natural environment
Regulatory Compliance	One Per Regulatory Issue	The feature of being in compliance with applicable regulations.
Health & Safety	One Per Health & Safety Issue	The feature of protecting people, including those engaged in operation and maintenance of the system, from undue risk of injury ca
Ease of Installation Feature	Mandatory for Oil Filter	The feature of being readily installed in or removed from service, in an acceptable time, using expected tools and facilities, by a pe
Optimal Product Configuration Feature	One Per Product Configuration	The feature of having an optimal portfolio of product physical configurations available.
Market-Application-Coverage Feature	One Per Seg-Applic-Product Combination	The feature of having a product configuration to cover an application in a market segment.
Manufacturability Feature	One per Production Plan Component	The feature of being producible at targeted production volume levels, by effective manufacturing processes, at acceptable levels of
Market-Distribution Coverage Feature	One per Seg-Channel-Package-Product Config. Combination	The feature, for targeted market segment, being compatible with associated channels of commercial distribution, including packag
Market Segment	One per Segment	An identified market segment, based on geography, customer type, or other segmentation of potential customers (except for appli
Distribution Channel	One per Channel	A channel for the commercial distribution of product from the point of production to the point of end buyer purchase, including whol
Optimal		

Figure 2.24. Export All Objects in View and Choose Custom Template

Table 2: [Stakeholder Feature Attributes] System Features and their Feature Attributes ultimately define the trade space in which all system design trade-offs, optimization's, and other decisions, comparisons, or fitness judgments are expressed and evaluated. Feature values are further specified or quantified by Feature Attributes, which are described in the terminology and concepts relevant to Stakeholders. These are therefore not always technical or objective in nature. This table requires to create folders which contain Feature, Feature Attribute and Temporary Assembly.

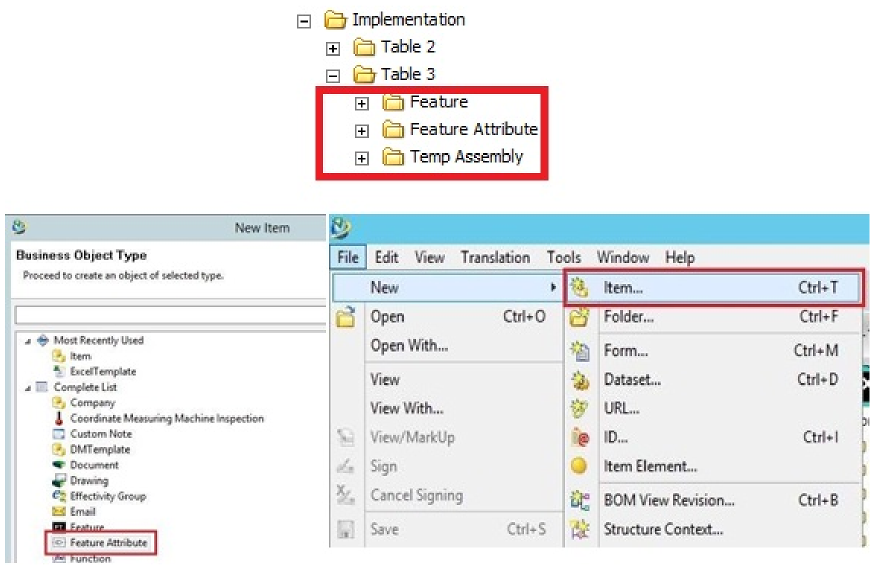


Figure 2.25. Create Folders and Feature Attributes

As all the features were already created it is easy to just copy and paste in the desired folder. The above figure shows the steps involved in creating feature attributes.

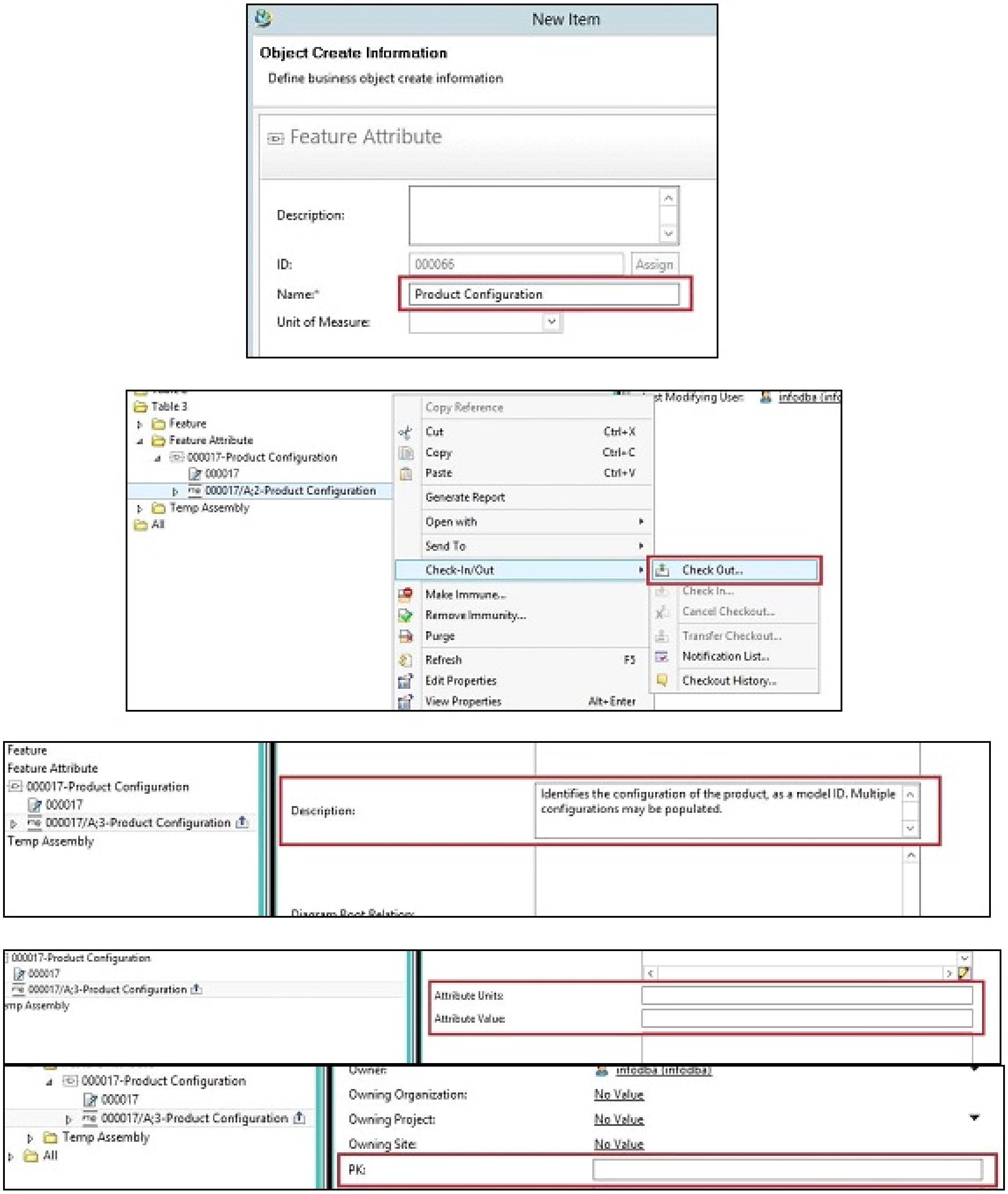


Figure 2.26. Steps to Configure Feature Attributes

This figure shows an example of a feature attribute (Product configuration) the related description needed and the options of properties if needed to fill according to the requirement. Repeat the above procedure for all the feature attribute item revisions.

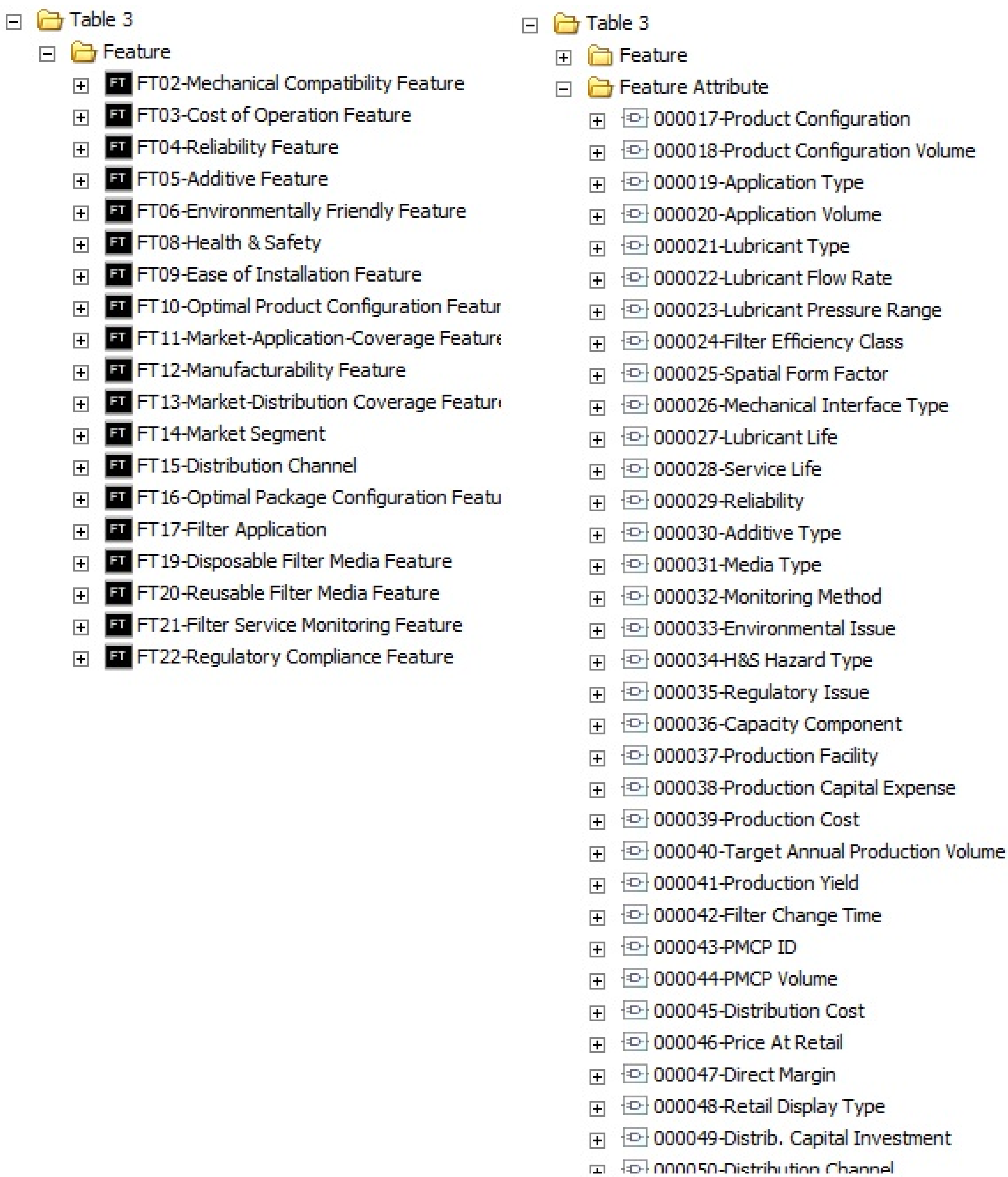


Figure 2.27. List of All Features and Feature Attributes

Now after the list is prepared we start arranging the features and feature attributes in structure manager.

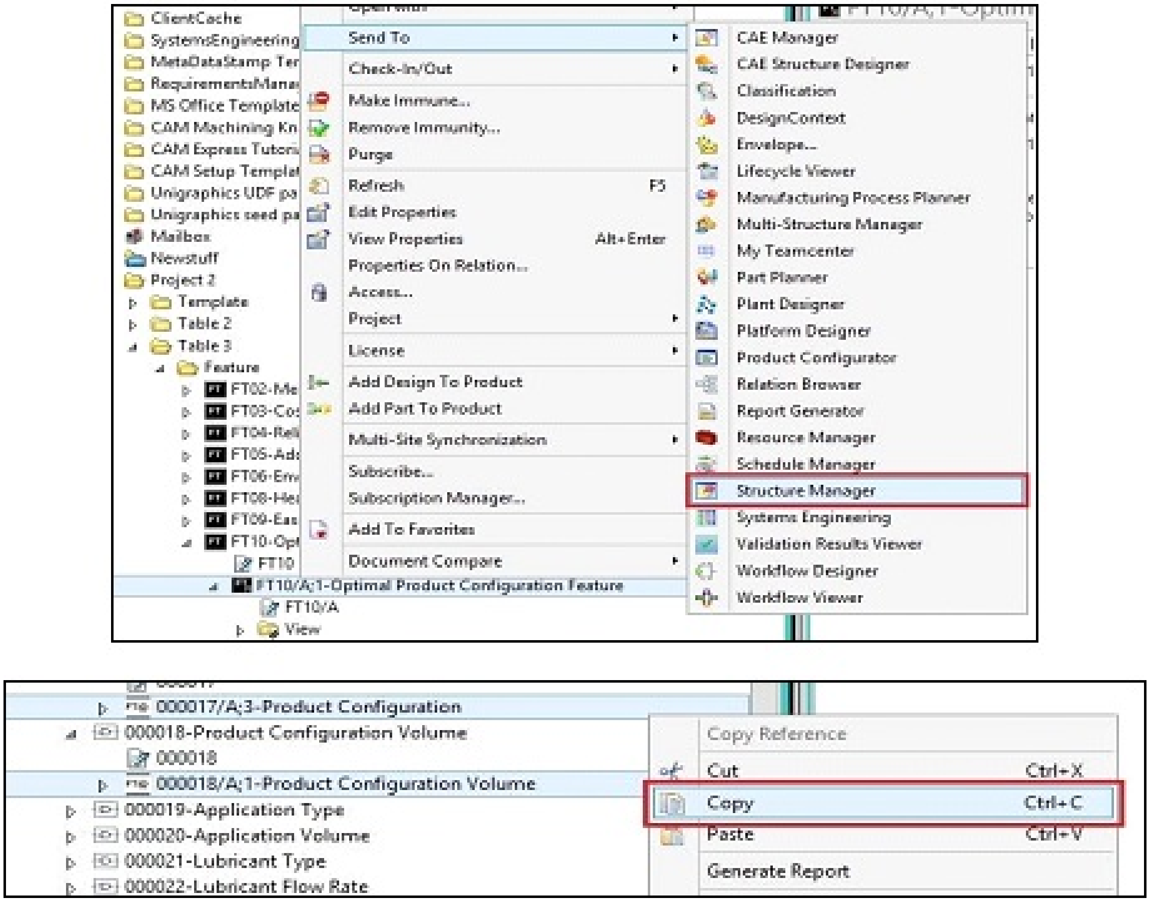
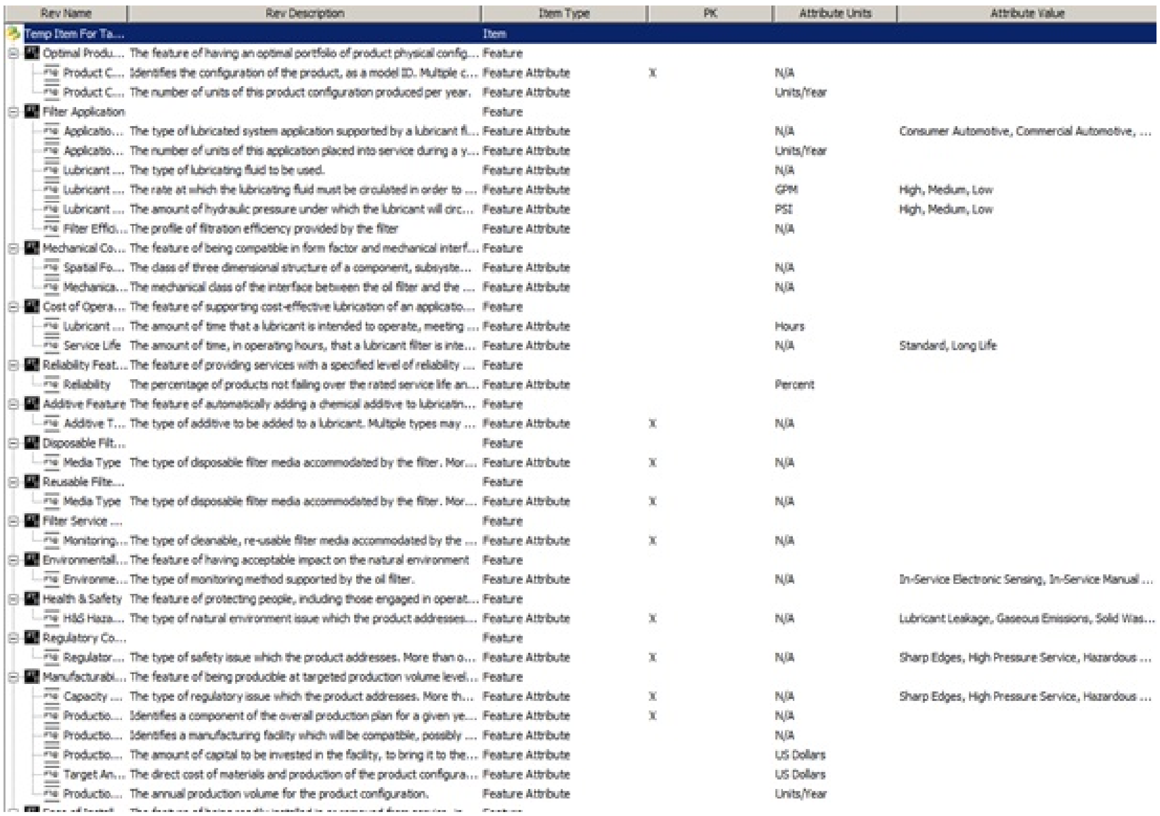


Figure 2.28. Group Feature and Feature Attributes in Structure

The above figure shows the steps involved in grouping the feature and feature attributes. Repeat these steps for the rest of the features and feature attributes. Create an item and paste all the features then send to structure manager.



Rev Name	Rev Description	Item Type	PK	Attribute Units	Attribute Value
Temp Item For Ta...		Item			
Optimal Produ...	The feature of having an optimal portfolio of product physical config...	Feature			
Product C...	Identifies the configuration of the product, as a model ID. Multiple c...	Feature Attribute	X	N/A	
Product C...	The number of units of this product configuration produced per year.	Feature Attribute		Units/Year	
Filter Application		Feature			
Applicatio...	The type of lubricated system application supported by a lubricant fi...	Feature Attribute		N/A	Consumer Automotive, Commercial Automotive, ...
Applicatio...	The number of units of this application placed into service during a y...	Feature Attribute		Units/Year	
Lubricant ...	The type of lubricating fluid to be used.	Feature Attribute		N/A	
Lubricant ...	The rate at which the lubricating fluid must be circulated in order to ...	Feature Attribute		GPM	High, Medium, Low
Lubricant ...	The amount of hydraulic pressure under which the lubricant will circ...	Feature Attribute		PSI	High, Medium, Low
Filter Effici...	The profile of filtration efficiency provided by the filter	Feature Attribute		N/A	
Mechanical Co...	The feature of being compatible in form factor and mechanical interf...	Feature			
Spatial Fo...	The class of three dimensional structure of a component, subsyste...	Feature Attribute		N/A	
Mechanica...	The mechanical class of the interface between the oil filter and the ...	Feature Attribute		N/A	
Cost of Opera...	The feature of supporting cost-effective lubrication of an applicatio...	Feature			
Lubricant ...	The amount of time that a lubricant is intended to operate, meeting ...	Feature Attribute		Hours	
Service Life	The amount of time, in operating hours, that a lubricant filter is inte...	Feature Attribute		N/A	Standard, Long Life
Reliability Feat...	The feature of providing services with a specified level of reliability ...	Feature			
Reliability	The percentage of products not failing over the rated service life an...	Feature Attribute		Percent	
Additive Feature	The feature of automatically adding a chemical additive to lubricatin...	Feature			
Additive T...	The type of additive to be added to a lubricant. Multiple types may ...	Feature Attribute	X	N/A	
Disposable Filt...		Feature			
Media Type	The type of disposable filter media accommodated by the filter. Mor...	Feature Attribute	X	N/A	
Reusable Filte...		Feature			
Media Type	The type of disposable filter media accommodated by the filter. Mor...	Feature Attribute	X	N/A	
Filter Service ...		Feature			
Monitoring...	The type of cleanable, re-usable filter media accommodated by the ...	Feature Attribute	X	N/A	
Environmentall...	The feature of having acceptable impact on the natural environment	Feature			
Environme...	The type of monitoring method supported by the oil filter.	Feature Attribute		N/A	In-Service Electronic Sensing, In-Service Manual ...
Health & Safety	The feature of protecting people, including those engaged in operat...	Feature			
H&S Haza...	The type of natural environment issue which the product addresses...	Feature Attribute	X	N/A	Lubricant Leakage, Gaseous Emissions, Solid Was...
Regulatory Co...		Feature			
Regulator...	The type of safety issue which the product addresses. More than o...	Feature Attribute	X	N/A	Sharp Edges, High Pressure Service, Hazardous ...
Manufacturabi...	The feature of being producible at targeted production volume level...	Feature			
Capacity ...	The type of regulatory issue which the product addresses. More th...	Feature Attribute	X	N/A	Sharp Edges, High Pressure Service, Hazardous ...
Productio...	Identifies a component of the overall production plan for a given ye...	Feature Attribute	X	N/A	
Productio...	Identifies a manufacturing facility which will be compatible, possibly ...	Feature Attribute		N/A	
Productio...	The amount of capital to be invested in the facility, to bring it to the...	Feature Attribute		US Dollars	
Target An...	The direct cost of materials and production of the product configura...	Feature Attribute		US Dollars	
Productio...	The annual production volume for the product configuration.	Feature Attribute		Units/Year	

Figure 2.29. Final Assembly in Structure Assembly

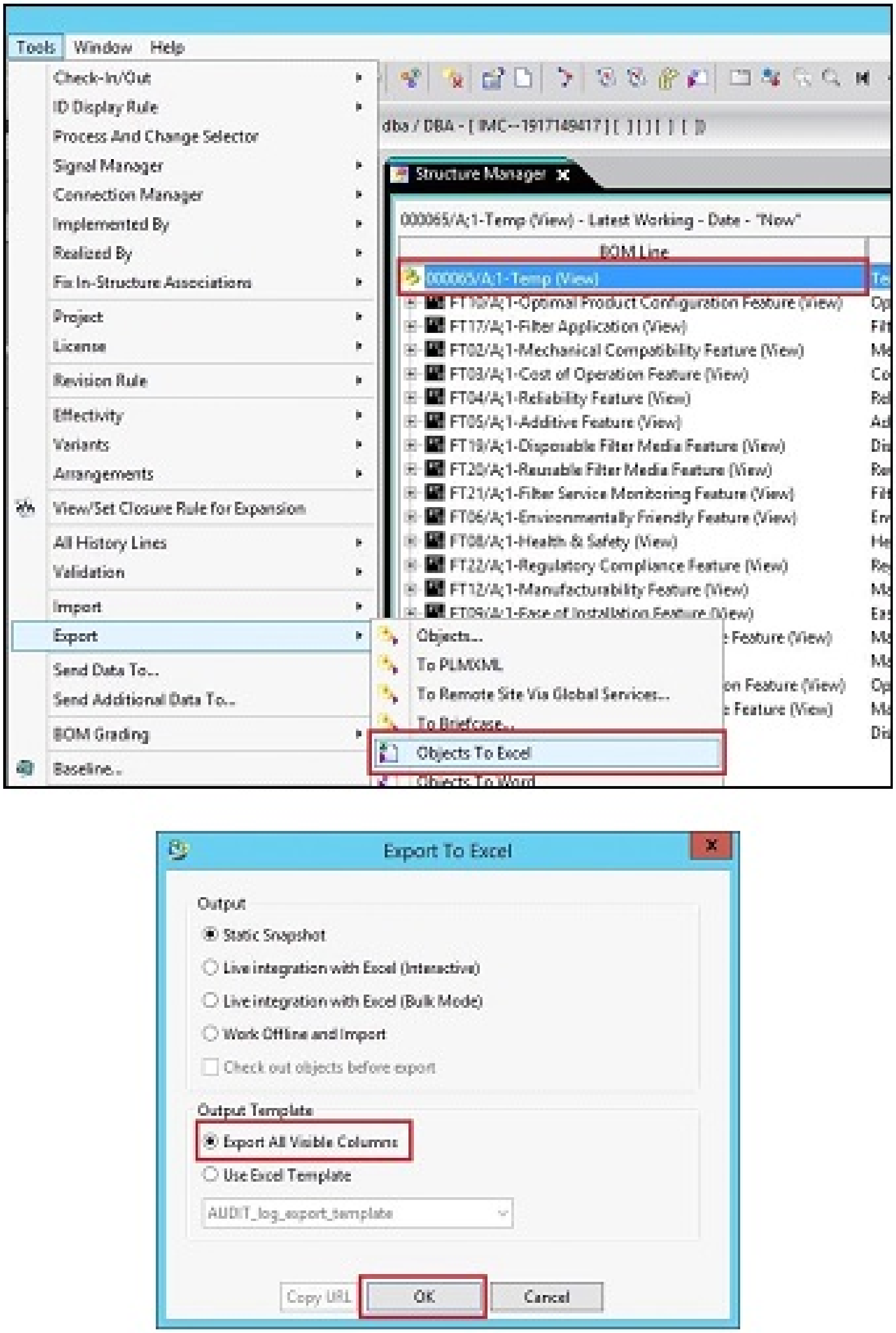


Figure 2.30. Export to Excel, Use Export All Visible columns

Once the columns and the order of the items are set the assembly is ready to export.

Feature	Feature Attribute	Multi-Instance	Attribute Definition	Attribute Units	
Optimal Product Configuration Featu	Product Configuration	X	Identifies the configuration of the product, as a model ID. Multiple configurations may be populated.	N/A	
Optimal Product Configuration Featu	Product Configuration Volume		The number of units of this product configuration produced per year.	Units/Year	
Filter Application	Application Type	X	The type of lubricated system application supported by a lubricant filtration system. More than one type may be instantiated for a single p	N/A	Consumer Auton
Filter Application	Application Volume		The number of units of this application placed into service during a year.	Units/Year	
Filter Application	Lubricant Type		The type of lubricating fluid to be used.	N/A	
Filter Application	Lubricant Flow Rate		The rate at which the lubricating fluid must be circulated in order to meet equipment lubrication objectives.	GPM	High, Medium, L
Filter Application	Lubricant Pressure Range		The amount of hydraulic pressure under which the lubricant will circulate.	PSI	High, Medium, L
Filter Application	Filter Efficiency Class		The profile of filtration efficiency provided by the filter	N/A	
Mechanical Compatibility Feature	Spatial Form Factor		The class of three dimensional structure of a component, subsystem, or space within a system reserved for a component or subsystem.	N/A	
Mechanical Compatibility Feature	Mechanical Interface Type		The mechanical class of the interface between the oil filter and the equipment to which it is connected.	N/A	
Cost of Operation Feature	Lubricant Life		The amount of time that a lubricant is intended to operate, meeting requirements within the specified environment, before it is replaced	Hours	
Cost of Operation Feature	Service Life		The amount of time, in operating hours, that a lubricant filter is intended to operate, meeting requirements within the specified environ	N/A	Standard, Long L
Reliability Feature	Reliability		The percentage of products not failing over the rated service life and application of the product.	Percent	
Additive Feature	Additive Type	X	The type of additive to be added to a lubricant. Multiple types may be populated.	N/A	
Disposable Filter Media Feature	Media Type	X	The type of disposable filter media accommodated by the filter. More than one type may be populated.	N/A	
Reusable Filter Media Feature	Media Type	X	The type of disposable filter media accommodated by the filter. More than one type may be populated.	N/A	
Filter Service Monitoring Feature	Monitoring Method	X	The type of cleanable, re-usable filter media accommodated by the filter. More than one type may be populated.	N/A	
Environmentally Friendly Feature	Environmental Issue		The type of monitoring method supported by the oil filter.	N/A	In-Service Electr
Health & Safety	H&S Hazard Type	X	The type of natural environment issue which the product addresses. More than one value may be populated.	N/A	Lubricant Leakag
Regulatory Compliance Feature	Regulatory Issue	X	The type of safety issue which the product addresses. More than one value may be populated.	N/A	Sharp Edges, Hig
Manufacturability Feature	Capacity Component	X	The type of regulatory issue which the product addresses. More than one value may be populated.	N/A	Sharp Edges, Hig
Manufacturability Feature	Production Facility	X	Identifies a component of the overall production plan for a given year, across multiple product configurations and production facilities, in	N/A	
Manufacturability Feature	Production Capital Expense		Identifies a manufacturing facility which will be compatible, possibly through investment of capital, with the required production. More t	N/A	

Figure 2.31. Final Assembly for Table 2

Table 3: [Detail Requirements] The requirements Statements for the Oil filter System describe the physical behaviours it must exhibit during its physical interactions with external systems.

To create this table first a default template is created along with folders containing Logical Systems block (contains all other systems), Interactions, Requirement Statement and Final Assembly.

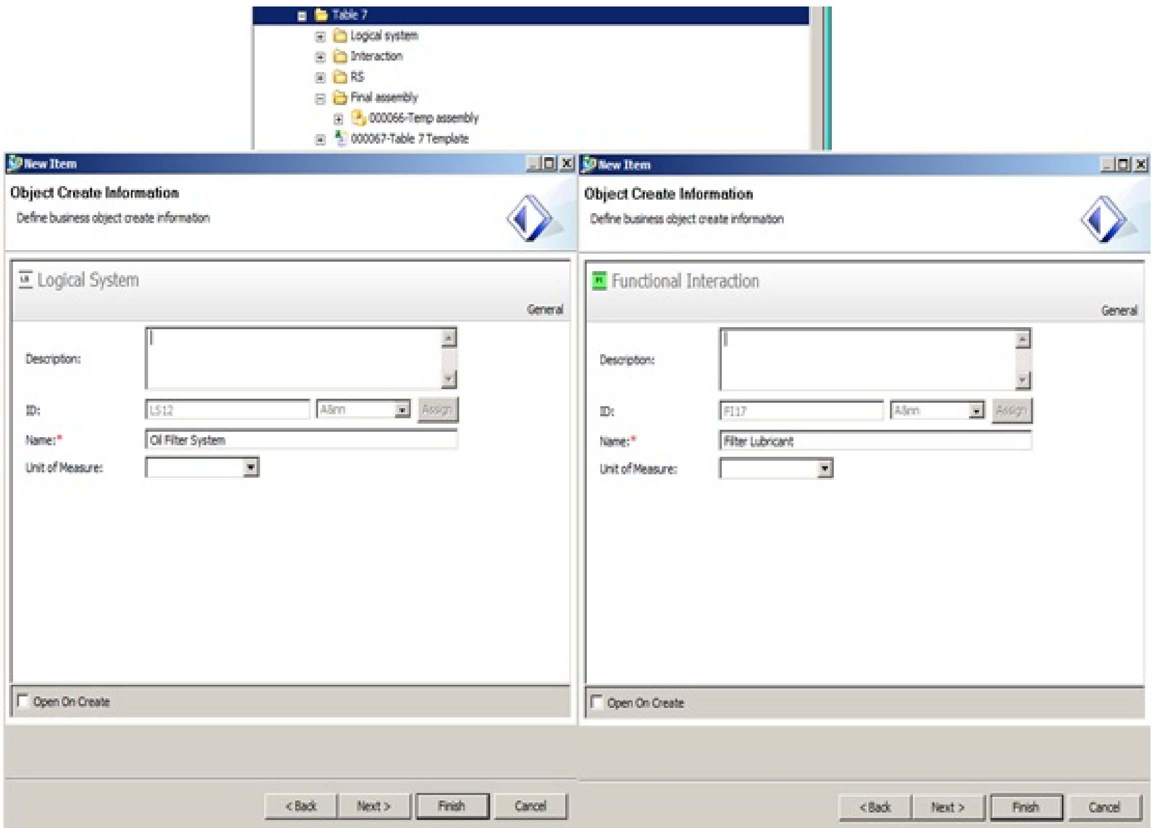


Figure 2.32. Create Custom Folders, Items for Logical Systems and Functional Interactions

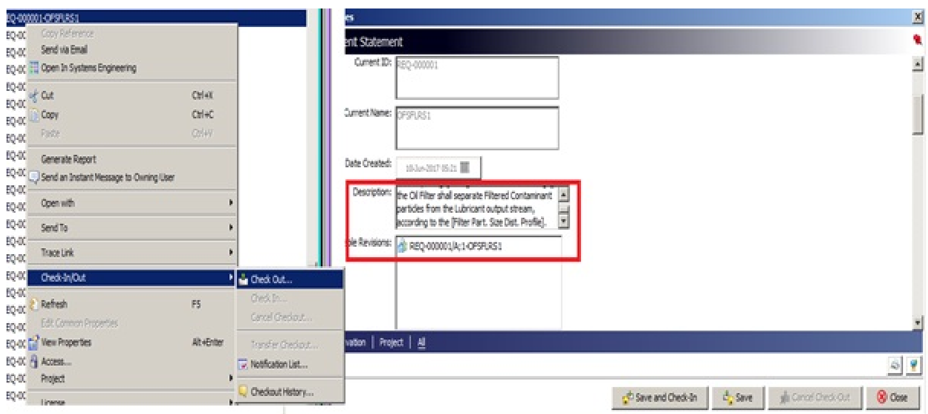


Figure 2.33. Configure Requirement Statements

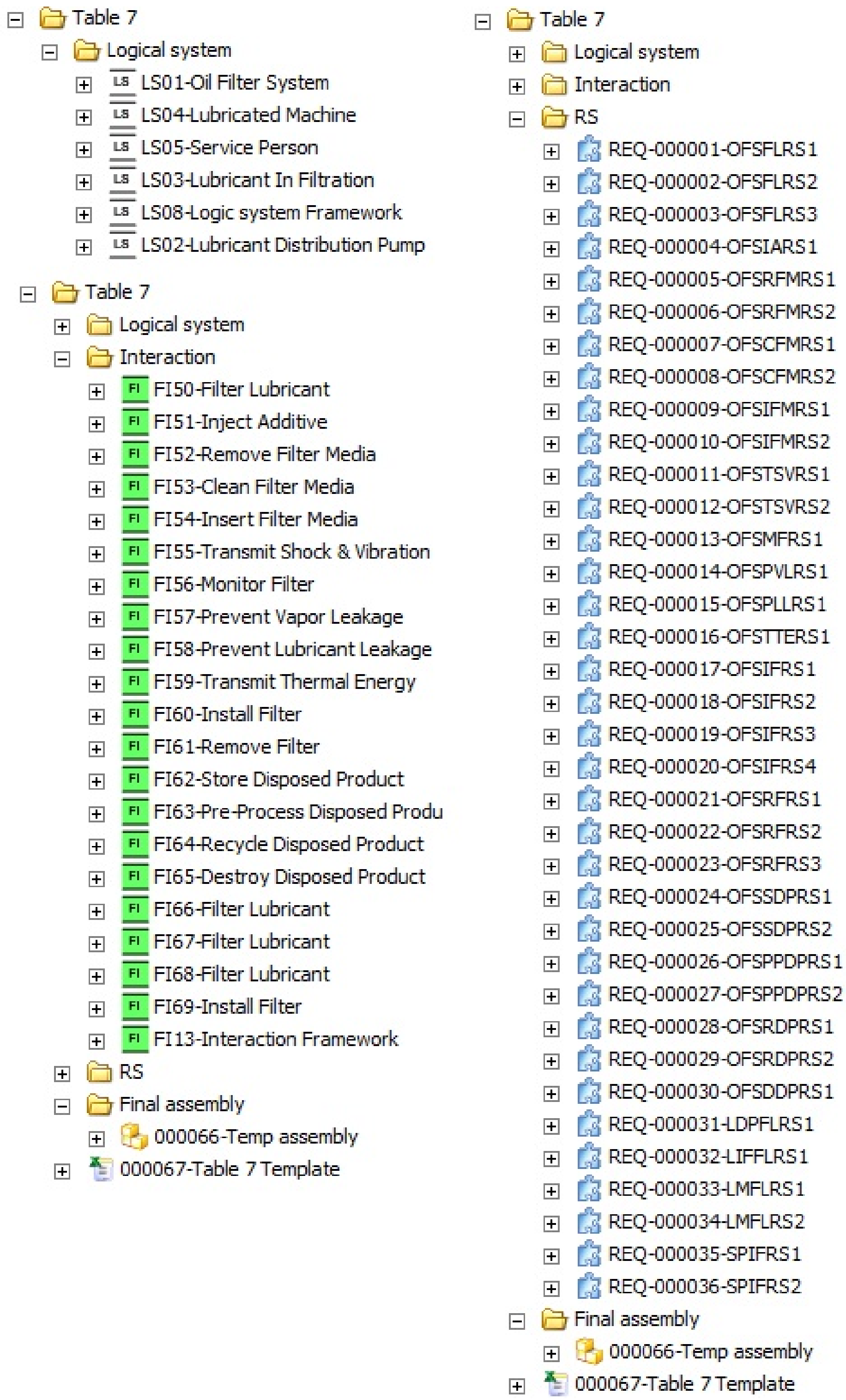
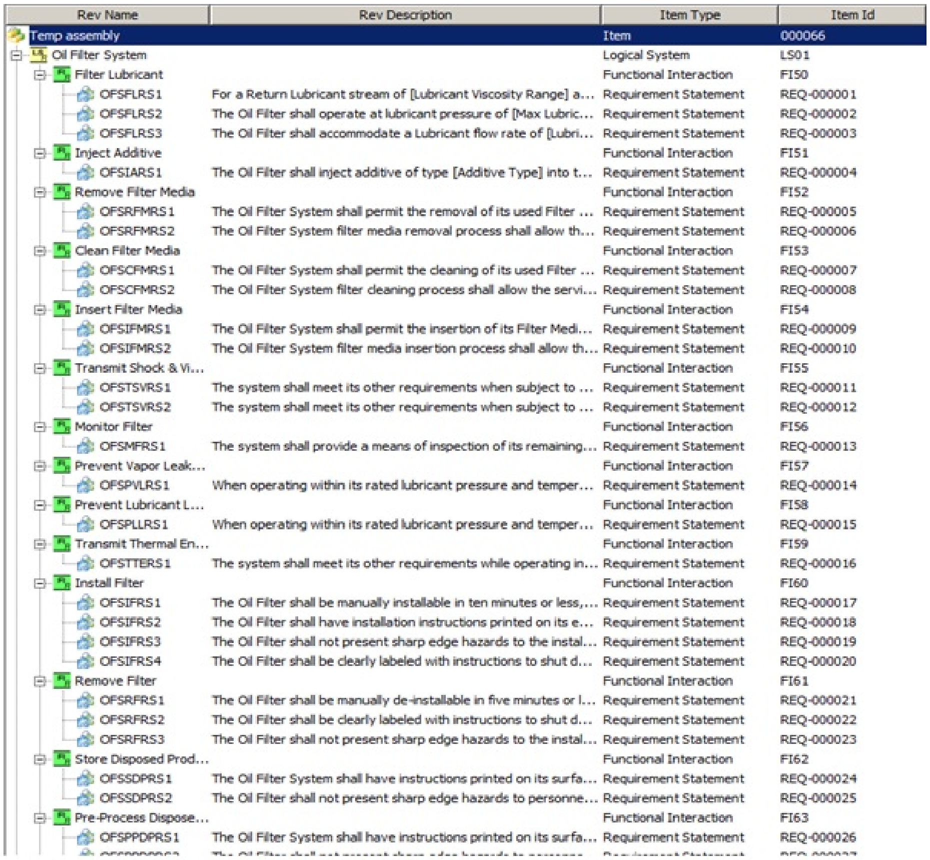


Figure 2.34. List of All Items Created for Logical System, Interaction and Specific Required Statements



Rev Name	Rev Description	Item Type	Item Id
Temp assembly		Item	000066
Oil Filter System		Logical System	LS01
Filter Lubricant		Functional Interaction	FI50
OFSFLRS1	For a Return Lubricant stream of [Lubricant Viscosity Range] a...	Requirement Statement	REQ-000001
OFSFLRS2	The Oil Filter shall operate at lubricant pressure of [Max Lubric...	Requirement Statement	REQ-000002
OFSFLRS3	The Oil Filter shall accommodate a Lubricant flow rate of [Lubri...	Requirement Statement	REQ-000003
Inject Additive		Functional Interaction	FI51
OFSIARS1	The Oil Filter shall inject additive of type [Additive Type] into t...	Requirement Statement	REQ-000004
Remove Filter Media		Functional Interaction	FI52
OFSRFMRS1	The Oil Filter System shall permit the removal of its used Filter ...	Requirement Statement	REQ-000005
OFSRFMRS2	The Oil Filter System filter media removal process shall allow th...	Requirement Statement	REQ-000006
Clean Filter Media		Functional Interaction	FI53
OFSCFMRS1	The Oil Filter System shall permit the cleaning of its used Filter ...	Requirement Statement	REQ-000007
OFSCFMRS2	The Oil Filter System filter cleaning process shall allow the servi...	Requirement Statement	REQ-000008
Insert Filter Media		Functional Interaction	FI54
OFSIFMRS1	The Oil Filter System shall permit the insertion of its Filter Medi...	Requirement Statement	REQ-000009
OFSIFMRS2	The Oil Filter System filter media insertion process shall allow th...	Requirement Statement	REQ-000010
Transmit Shock & Vi...		Functional Interaction	FI55
OFSTSVRS1	The system shall meet its other requirements when subject to ...	Requirement Statement	REQ-000011
OFSTSVRS2	The system shall meet its other requirements when subject to ...	Requirement Statement	REQ-000012
Monitor Filter		Functional Interaction	FI56
OFSMFRS1	The system shall provide a means of inspection of its remaining...	Requirement Statement	REQ-000013
Prevent Vapor Leak...		Functional Interaction	FI57
OFSPVLRS1	When operating within its rated lubricant pressure and temper...	Requirement Statement	REQ-000014
Prevent Lubricant L...		Functional Interaction	FI58
OFSPLLRS1	When operating within its rated lubricant pressure and temper...	Requirement Statement	REQ-000015
Transmit Thermal En...		Functional Interaction	FI59
OFSTTERS1	The system shall meet its other requirements while operating in...	Requirement Statement	REQ-000016
Install Filter		Functional Interaction	FI60
OFSIFRS1	The Oil Filter shall be manually installable in ten minutes or less,...	Requirement Statement	REQ-000017
OFSIFRS2	The Oil Filter shall have installation instructions printed on its e...	Requirement Statement	REQ-000018
OFSIFRS3	The Oil Filter shall not present sharp edge hazards to the instal...	Requirement Statement	REQ-000019
OFSIFRS4	The Oil Filter shall be clearly labeled with instructions to shut d...	Requirement Statement	REQ-000020
Remove Filter		Functional Interaction	FI61
OFSRFRS1	The Oil Filter shall be manually de-installable in five minutes or l...	Requirement Statement	REQ-000021
OFSRFRS2	The Oil Filter shall be clearly labeled with instructions to shut d...	Requirement Statement	REQ-000022
OFSRFRS3	The Oil Filter shall not present sharp edge hazards to the instal...	Requirement Statement	REQ-000023
Store Disposed Prod...		Functional Interaction	FI62
OFSSDPRS1	The Oil Filter System shall have instructions printed on its surfa...	Requirement Statement	REQ-000024
OFSSDPRS2	The Oil Filter shall not present sharp edge hazards to personne...	Requirement Statement	REQ-000025
Pre-Process Dispose...		Functional Interaction	FI63
OFSPPDPRS1	The Oil Filter System shall have instructions printed on its surfa...	Requirement Statement	REQ-000026

Figure 2.35. Final Assembly of Table 3 in Structure Manager

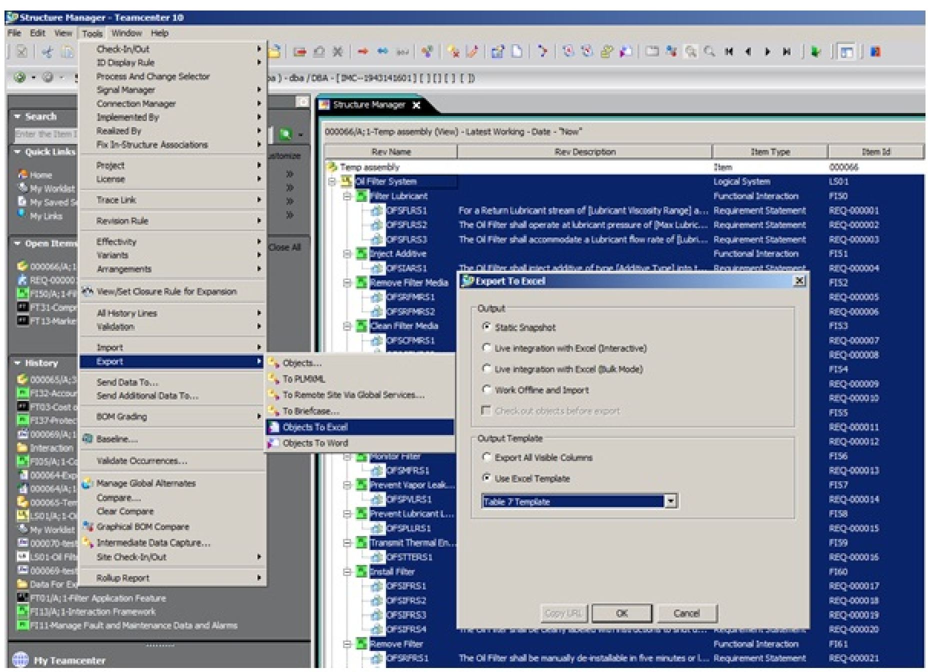


Figure 2.36. Export to Excel Table 3

DETAIL REQUIREMENTS

Interaction	Role	ID	Description
Filter Lubricant	Oil Filter System	REQ-000001	For a Return Lubricant stream of [Lubricant Viscosity Range] and [Lubricant Pressure Range], the Oil Filter shall separate Filtered Contaminant particles from the Lubricant c
Filter Lubricant	Oil Filter System	REQ-000002	The Oil Filter shall operate at lubricant pressure of [Max Lubricant Pressure] with structural failure rates less than [Max Structural Failure Rate] over an in-service life of [Min S
Filter Lubricant	Oil Filter System	REQ-000003	The Oil Filter shall accommodate a Lubricant flow rate of [Lubricant Flow Rate].
Inject Additive	Oil Filter System	REQ-000004	The Oil Filter shall inject additive of type [Additive Type] into the Lubricant flow, at a rate of [Additive Injection Rate] per unit of lubricant flow, over the service life of the filter el
Remove Filter Med	Oil Filter System	REQ-000005	The Oil Filter System shall permit the removal of its used Filter Media.
Remove Filter Med	Oil Filter System	REQ-000006	The Oil Filter System filter media removal process shall allow the service person to avoid direct contact contamination with filtered contaminants and lubricant.
Clean Filter Media	Oil Filter System	REQ-000007	The Oil Filter System shall permit the cleaning of its used Filter Media, for reuse purposes, using cleaning solvent and method of type [Filter Media Cleaning Method and Sol
Clean Filter Media	Oil Filter System	REQ-000008	The Oil Filter System filter cleaning process shall allow the service person to avoid direct contact contamination with filtered contaminants and lubricant.
Insert Filter Media	Oil Filter System	REQ-000009	The Oil Filter System shall permit the insertion of its Filter Media, of type [Filter Media Type].
Insert Filter Media	Oil Filter System	REQ-000010	The Oil Filter System filter media insertion process shall allow the service person to avoid direct contact contamination with filtered contaminants and lubricant.
Transmit Shock &	Oil Filter System	REQ-000011	The system shall meet its other requirements when subject to a vibration spectrum not exceeding [Max Vibration Spectrum] during its in-service life.
Transmit Shock &	Oil Filter System	REQ-000012	The system shall meet its other requirements when subject to shock intensity and frequency not exceeding [Max Shock Intensity and Frequency] during its in-service life.
Monitor Filter	Oil Filter System	REQ-000013	The system shall provide a means of inspection of its remaining service life before requiring servicing, using [Filter Monitoring Method].
Prevent Vapor Lea	Oil Filter System	REQ-000014	When operating within its rated lubricant pressure and temperature, at altitudes not exceeding [Max Service Altitude], the system shall maintain Vapor Leakage to the ambie
Prevent Lubricant	Oil Filter System	REQ-000015	When operating within its rated lubricant pressure and temperature, at altitudes not exceeding [Max Service Altitude], the system shall maintain Fluid Leakage to the surrour
Transmit Thermal	Oil Filter System	REQ-000016	The system shall meet its other requirements while operating in external ambient air temperatures of [External Temperature Range] and lubricant temperatures of [Lubricant T
Install Filter	Oil Filter System	REQ-000017	The Oil Filter shall be manually installable in ten minutes or less, using only a screwdriver.
Install Filter	Oil Filter System	REQ-000018	The Oil Filter shall have installation instructions printed on its exterior surface, in [National Language] language.
Install Filter	Oil Filter System	REQ-000019	The Oil Filter shall not present sharp edge hazards to the installer during the installation process.
Install Filter	Oil Filter System	REQ-000020	The Oil Filter shall be clearly labeled with instructions to shut down pressurized equipment prior to installation.
Remove Filter	Oil Filter System	REQ-000021	The Oil Filter shall be manually de-installable in five minutes or less, using only a screwdriver.

Figure 2.37. Final Assembly Generated for Table 3

3. SUMMARY OF RESULTS AND VALIDATION

3.1 Summary of Results

In this study we have successfully implemented the S*Metamodel in Teamcenter and extracted the system requirements from the model.

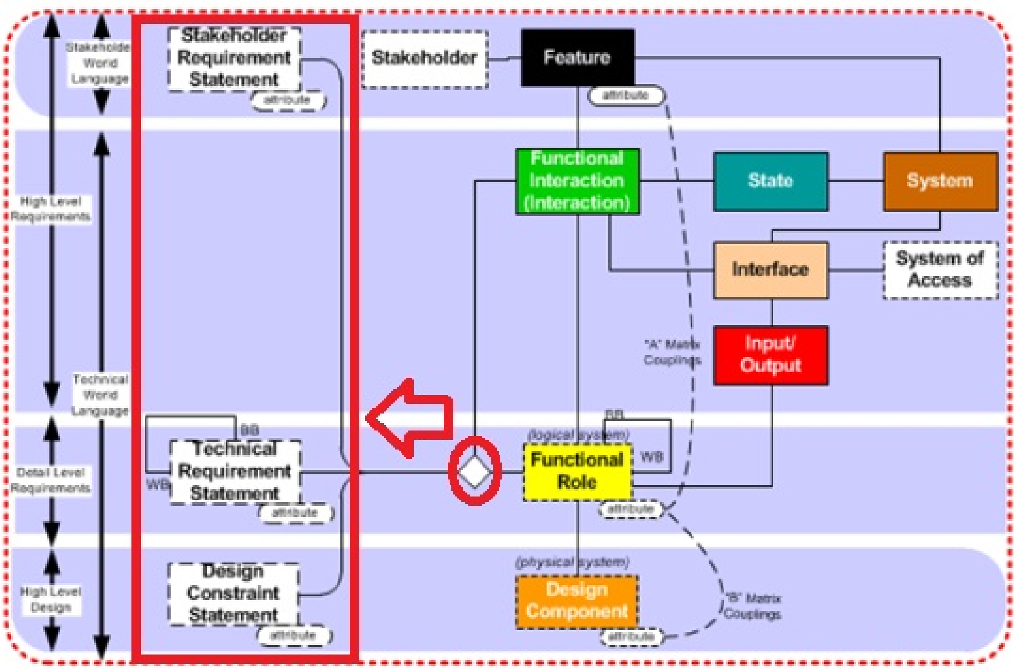


Figure 3.1. Extraction of Requirements

The above figure 3.1 clearly suggests that once the S*Metamodel is implemented, list of requirements can be generated from the model. Therefore to prove our integration we have extracted these tables. There are three tables that have been configured for automatic generation which are Feature definitions table, Detail Requirements table and Stakeholder Feature Attributes table. These tables where specifically chosen as they describe all the requirements of the system and cover all physical behaviour's the oil filter system shall exhibit during its physical interactions with external systems. The requirement tables represent core content for a typical systems engineering report. With the help of the automatic report generation tool, it is possible to prepare the entire report within one single system, the PLM system, to ensure a single reliable data source for an organization.

Feature Definitions

Feature	Configuration Population Rule	Definition
Filter Application Feature	One per Filter Application Type	The feature of maintaining a lubricating fluid at a required level of cleanliness while it is in service in a specified application, includir
Mechanical Compatibility Feature	Mandatory for Oil Filter	The feature of being compatible in form factor and mechanical interface with the system in which the system will be installed.
Cost of Operation Feature	Mandatory for Oil Filter	The feature of supporting cost-effective lubrication of an application, by minimizing the cost of lubrication consumables per operatir
Reliability Feature	Mandatory for Oil Filter	The feature of providing services with a specified level of reliability over the normal operating life of a system.
Additive Feature	One Per Additive Type	The feature of automatically adding a chemical additive to lubricating fluid at a specified rate, to accomplish the purpose of the add
Environmentally Friendly Feature	One Per Environmental Issue	The feature of having acceptable impact on the natural environment
Regulatory Compliance	One Per Regulatory Issue	The feature of being in compliance with applicable regulations.
Health & Safety	One Per Health & Safety Issue	The feature of protecting people, including those engaged in operation and maintenance of the system, from undue risk of injury ca
Ease of Installation Feature	Mandatory for Oil Filter	The feature of being readily installed in or removed from service, in an acceptable time, using expected tools and facilities, by a pe
Optimal Product Configuration Feature	One Per Product Configuration	The feature of having an optimal portfolio of product physical configurations available.
Market-Application-Coverage Feature	One Per Seg-Applic-Product Combination	The feature of having a product configuration to cover an application in a market segment.
Manufacturabilit y Feature	One per Production Plan Component	The feature of being producible at targeted production volume levels, by effective manufacturing processes, at acceptable levels of
Market-Distribution Coverage Feature	One per Seg-Channel-Package-Product Config. Combination	The feature, for targeted market segment, being compatible with associated channels of commercial distribution, including packag
Market Segment	One per Segment	An identified market segment, based on geography, customer type, or other segmentation of potential customers (except for appli
Distribution Channel	One per Channel	A channel for the commercial distribution of product from the point of production to the point of end buyer purchase, including whol
Optimal		

Figure 3.2. Feature Definitions Table

Feature	Feature Attribute	Multi-Instance	Attribute Definition	Attribute Units	
Optimal Product Configuration Featu	Product Configuration	X	Identifies the configuration of the product, as a model ID. Multiple configurations may be populated.	N/A	
Optimal Product Configuration Featu	Product Configuration Volume		The number of units of this product configuration produced per year.	Units/Year	
Filter Application	Application Type	X	The type of lubricated system application supported by a lubricant filtration system. More than one type may be instantiated for a single p	N/A	Consumer Auton
Filter Application	Application Volume		The number of units of this application placed into service during a year.	Units/Year	
Filter Application	Lubricant Type		The type of lubricating fluid to be used.	N/A	
Filter Application	Lubricant Flow Rate		The rate at which the lubricating fluid must be circulated in order to meet equipment lubrication objectives.	GPM	High, Medium, L
Filter Application	Lubricant Pressure Range		The amount of hydraulic pressure under which the lubricant will circulate.	PSI	High, Medium, L
Filter Application	Filter Efficiency Class		The profile of filtration efficiency provided by the filter	N/A	
Mechanical Compatibility Feature	Spatial Form Factor		The class of three dimensional structure of a component, subsystem, or space within a system reserved for a component or subsystem.	N/A	
Mechanical Compatibility Feature	Mechanical Interface Type		The mechanical class of the interface between the oil filter and the equipment to which it is connected.	N/A	
Cost of Operation Feature	Lubricant Life		The amount of time that a lubricant is intended to operate, meeting requirements within the specified environment, before it is replaced	Hours	
Cost of Operation Feature	Service Life		The amount of time, in operating hours, that a lubricant filter is intended to operate, meeting requirements within the specified environ	N/A	Standard, Long L
Reliability Feature	Reliability		The percentage of products not failing over the rated service life and application of the product.	Percent	
Additive Feature	Additive Type	X	The type of additive to be added to a lubricant. Multiple types may be populated.	N/A	
Disposable Filter Media Feature	Media Type	X	The type of disposable filter media accommodated by the filter. More than one type may be populated.	N/A	
Reusable Filter Media Feature	Media Type	X	The type of disposable filter media accommodated by the filter. More than one type may be populated.	N/A	
Filter Service Monitoring Feature	Monitoring Method	X	The type of cleanable, re-usable filter media accommodated by the filter. More than one type may be populated.	N/A	
Environmentally Friendly Feature	Environmental Issue		The type of monitoring method supported by the oil filter.	N/A	In-Service Electr
Health & Safety	H&S Hazard Type	X	The type of natural environment issue which the product addresses. More than one value may be populated.	N/A	Lubricant Leakag
Regulatory Compliance Feature	Regulatory Issue	X	The type of safety issue which the product addresses. More than one value may be populated.	N/A	Sharp Edges, Hig
Manufacturability Feature	Capacity Component	X	The type of regulatory issue which the product addresses. More than one value may be populated.	N/A	Sharp Edges, Hig
Manufacturability Feature	Production Facility	X	Identifies a component of the overall production plan for a given year, across multiple product configurations and production facilities, in	N/A	
Manufacturability Feature	Production Capital Expense		Identifies a manufacturing facility which will be compatible, possibly through investment of capital, with the required production. More t	N/A	

Figure 3.3. Stakeholders Requirement Table

There are three tables that have been configured for automatic generation which majorly cover the requirements of the Oil Filter System.

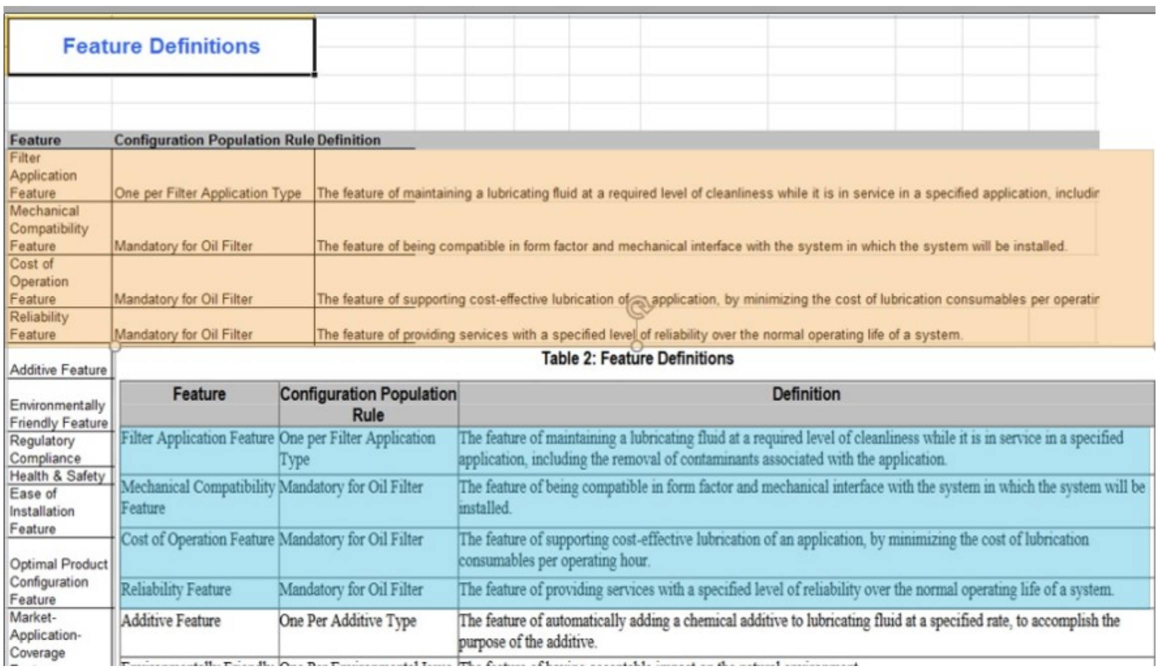
DETAIL REQUIREMENTS

Interaction	Role	ID	Description
Filter Lubricant	Oil Filter System	REQ-000001	For a Return Lubricant stream of [Lubricant Viscosity Range] and [Lubricant Pressure Range], the Oil Filter shall separate Filtered Contaminant particles from the Lubricant c
Filter Lubricant	Oil Filter System	REQ-000002	The Oil Filter shall operate at lubricant pressure of [Max Lubricant Pressure] with structural failure rates less than [Max Structural Failure Rate] over an in-service life of [Min S
Filter Lubricant	Oil Filter System	REQ-000003	The Oil Filter shall accommodate a Lubricant flow rate of [Lubricant Flow Rate].
Inject Additive	Oil Filter System	REQ-000004	The Oil Filter shall inject additive of type [Additive Type] into the Lubricant flow, at a rate of [Additive Injection Rate] per unit of lubricant flow, over the service life of the filter el
Remove Filter Med	Oil Filter System	REQ-000005	The Oil Filter System shall permit the removal of its used Filter Media.
Remove Filter Med	Oil Filter System	REQ-000006	The Oil Filter System filter media removal process shall allow the service person to avoid direct contact contamination with filtered contaminants and lubricant.
Clean Filter Media	Oil Filter System	REQ-000007	The Oil Filter System shall permit the cleaning of its used Filter Media, for reuse purposes, using cleaning solvent and method of type [Filter Media Cleaning Method and Sol
Clean Filter Media	Oil Filter System	REQ-000008	The Oil Filter System filter cleaning process shall allow the service person to avoid direct contact contamination with filtered contaminants and lubricant.
Insert Filter Media	Oil Filter System	REQ-000009	The Oil Filter System shall permit the insertion of its Filter Media, of type [Filter Media Type].
Insert Filter Media	Oil Filter System	REQ-000010	The Oil Filter System filter media insertion process shall allow the service person to avoid direct contact contamination with filtered contaminants and lubricant.
Transmit Shock &	Oil Filter System	REQ-000011	The system shall meet its other requirements when subject to a vibration spectrum not exceeding [Max Vibration Spectrum] during its in-service life.
Transmit Shock &	Oil Filter System	REQ-000012	The system shall meet its other requirements when subject to shock intensity and frequency not exceeding [Max Shock Intensity and Frequency] during its in-service life.
Monitor Filter	Oil Filter System	REQ-000013	The system shall provide a means of inspection of its remaining service life before requiring servicing, using [Filter Monitoring Method].
Prevent Vapor Lea	Oil Filter System	REQ-000014	When operating within its rated lubricant pressure and temperature, at altitudes not exceeding [Max Service Altitude], the system shall maintain Vapor Leakage to the ambie
Prevent Lubricant	Oil Filter System	REQ-000015	When operating within its rated lubricant pressure and temperature, at altitudes not exceeding [Max Service Altitude], the system shall maintain Fluid Leakage to the surrour
Transmit Thermal	Oil Filter System	REQ-000016	The system shall meet its other requirements while operating in external ambient air temperatures of [External Temperature Range] and lubricant temperatures of [Lubricant T
Install Filter	Oil Filter System	REQ-000017	The Oil Filter shall be manually installable in ten minutes or less, using only a screwdriver.
Install Filter	Oil Filter System	REQ-000018	The Oil Filter shall have installation instructions printed on its exterior surface, in [National Language] language.
Install Filter	Oil Filter System	REQ-000019	The Oil Filter shall not present sharp edge hazards to the installer during the installation process.
Install Filter	Oil Filter System	REQ-000020	The Oil Filter shall be clearly labeled with instructions to shut down pressurized equipment prior to installation.
Remove Filter	Oil Filter System	REQ-000021	The Oil Filter shall be manually de-installable in five minutes or less, using only a screwdriver.

Figure 3.4. Detail Requirements Table

3.2 Validation

We received a systems requirements document created by a professional systems engineers to define system high level requirements for the Global Oil Filter Product Line system family. The document communicates authoritative generic model within which specific product configurations are defined. (Credits: - ICTT system sciences) In this study we choose to generate 3 of the main requirement tables to generate from our integration and then later compare to validate our integration. We validate our results and validate by checking the amount of information generated from Teamcenter is accurate or not.



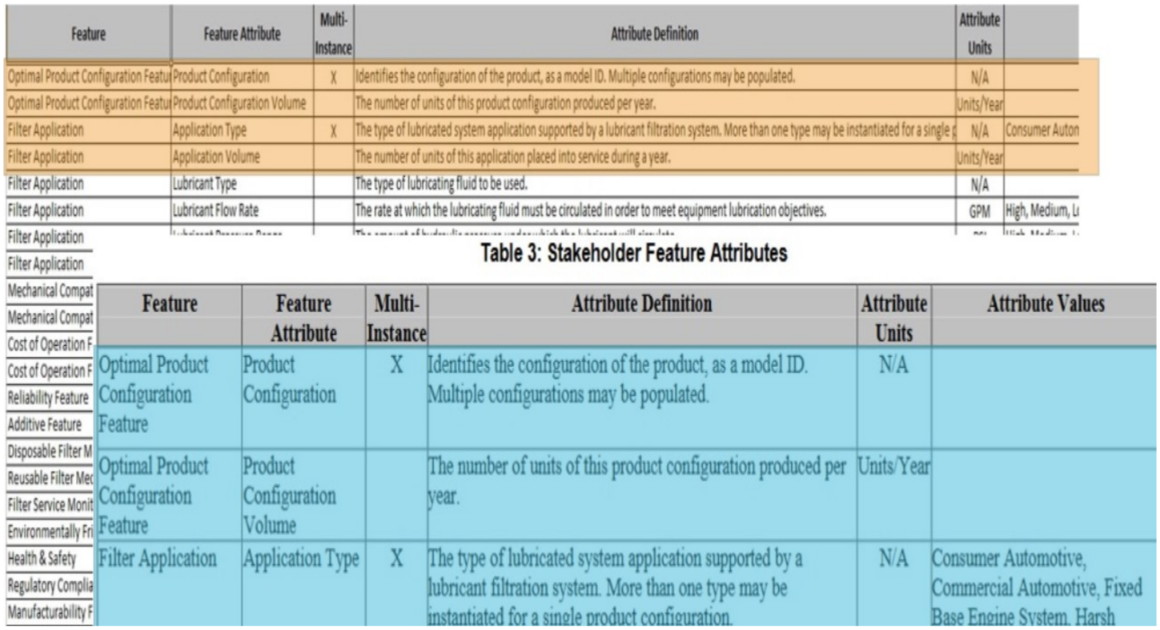
Feature Definitions

Feature	Configuration Population Rule	Definition
Filter Application Feature	One per Filter Application Type	The feature of maintaining a lubricating fluid at a required level of cleanliness while it is in service in a specified application, includir
Mechanical Compatibility Feature	Mandatory for Oil Filter	The feature of being compatible in form factor and mechanical interface with the system in which the system will be installed.
Cost of Operation Feature	Mandatory for Oil Filter	The feature of supporting cost-effective lubrication of application, by minimizing the cost of lubrication consumables per operatir
Reliability Feature	Mandatory for Oil Filter	The feature of providing services with a specified level of reliability over the normal operating life of a system.
Additive Feature		
Environmentally Friendly Feature		
Regulatory Compliance		
Health & Safety		
Ease of Installation Feature		
Optimal Product Configuration Feature		
Market-Application-Coverage		

Table 2: Feature Definitions

Feature	Configuration Population Rule	Definition
Filter Application Feature	One per Filter Application Type	The feature of maintaining a lubricating fluid at a required level of cleanliness while it is in service in a specified application, including the removal of contaminants associated with the application.
Mechanical Compatibility Feature	Mandatory for Oil Filter	The feature of being compatible in form factor and mechanical interface with the system in which the system will be installed.
Cost of Operation Feature	Mandatory for Oil Filter	The feature of supporting cost-effective lubrication of an application, by minimizing the cost of lubrication consumables per operating hour.
Reliability Feature	Mandatory for Oil Filter	The feature of providing services with a specified level of reliability over the normal operating life of a system.
Additive Feature	One Per Additive Type	The feature of automatically adding a chemical additive to lubricating fluid at a specified rate, to accomplish the purpose of the additive.

Figure 3.5. Comparison of Features Definitions Table,(Orange represents Document Generated from Integration and Blue represents Document Created by Professional System Engineer)

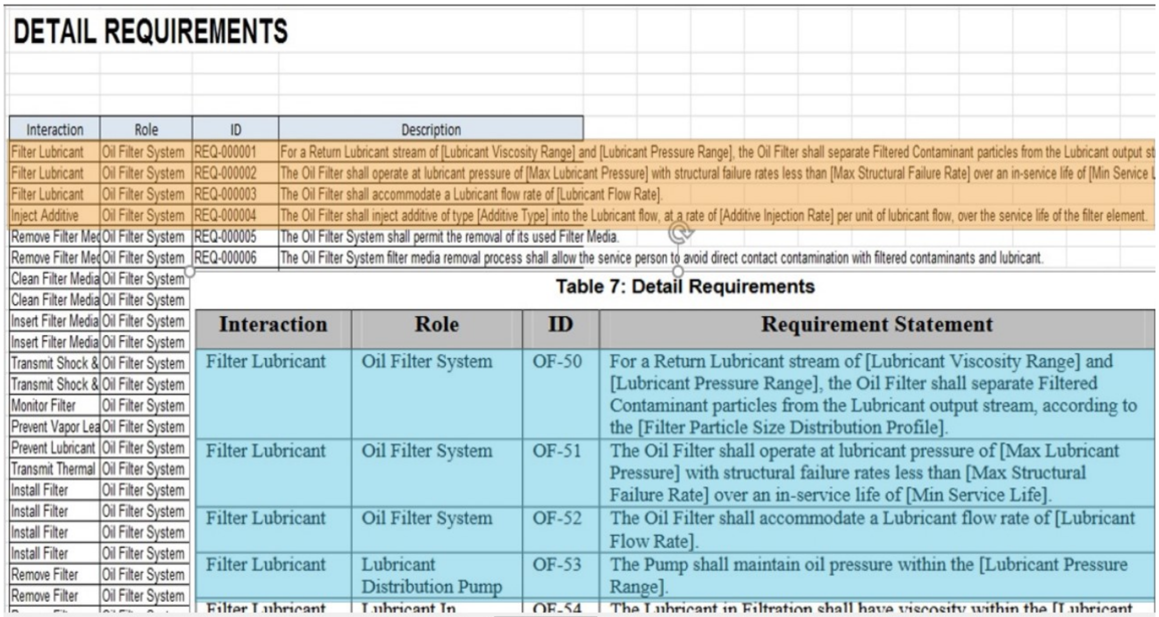


Feature	Feature Attribute	Multi-Instance	Attribute Definition	Attribute Units	
Optimal Product Configuration Featu	Product Configuration	X	Identifies the configuration of the product, as a model ID. Multiple configurations may be populated.	N/A	
Optimal Product Configuration Featu	Product Configuration Volume		The number of units of this product configuration produced per year.	Units/Year	
Filter Application	Application Type	X	The type of lubricated system application supported by a lubricant filtration system. More than one type may be instantiated for a single p	N/A	Consumer Auton
Filter Application	Application Volume		The number of units of this application placed into service during a year.	Units/Year	
Filter Application	Lubricant Type		The type of lubricating fluid to be used.	N/A	
Filter Application	Lubricant Flow Rate		The rate at which the lubricating fluid must be circulated in order to meet equipment lubrication objectives.	GPM	High, Medium, L
Filter Application					
Filter Application					
Mechanical Compat					
Mechanical Compat					
Cost of Operation F					
Cost of Operation F					
Reliability Feature					
Additive Feature					
Disposable Filter M					
Reusable Filter Mec					
Filter Service Monit					
Environmentally Fri					
Health & Safety					
Regulatory Complia					
Manufacturability F					

Table 3: Stakeholder Feature Attributes

Feature	Feature Attribute	Multi-Instance	Attribute Definition	Attribute Units	Attribute Values
Optimal Product Configuration Feature	Product Configuration	X	Identifies the configuration of the product, as a model ID. Multiple configurations may be populated.	N/A	
Optimal Product Configuration Feature	Product Configuration Volume		The number of units of this product configuration produced per year.	Units/Year	
Filter Application	Application Type	X	The type of lubricated system application supported by a lubricant filtration system. More than one type may be instantiated for a single product configuration.	N/A	Consumer Automotive, Commercial Automotive, Fixed Base Engine System, Harsh

Figure 3.6. Comparison of Stakeholders Requirement Table,(Orange represents Document Generated from Integration and Blue represents Document Created by Professional System Engineer)



DETAIL REQUIREMENTS

Interaction	Role	ID	Description
Filter Lubricant	Oil Filter System	REQ-000001	For a Return Lubricant stream of [Lubricant Viscosity Range] and [Lubricant Pressure Range], the Oil Filter shall separate Filtered Contaminant particles from the Lubricant output st
Filter Lubricant	Oil Filter System	REQ-000002	The Oil Filter shall operate at lubricant pressure of [Max Lubricant Pressure] with structural failure rates less than [Max Structural Failure Rate] over an in-service life of [Min Service L
Filter Lubricant	Oil Filter System	REQ-000003	The Oil Filter shall accommodate a Lubricant flow rate of [Lubricant Flow Rate].
Inject Additive	Oil Filter System	REQ-000004	The Oil Filter shall inject additive of type [Additive Type] into the Lubricant flow, at a rate of [Additive Injection Rate] per unit of lubricant flow, over the service life of the filter element.
Remove Filter Med	Oil Filter System	REQ-000005	The Oil Filter System shall permit the removal of its used Filter Media.
Remove Filter Med	Oil Filter System	REQ-000006	The Oil Filter System filter media removal process shall allow the service person to avoid direct contact contamination with filtered contaminants and lubricant.
Clean Filter Media	Oil Filter System		
Clean Filter Media	Oil Filter System		
Insert Filter Media	Oil Filter System		
Insert Filter Media	Oil Filter System		
Transmit Shock &	Oil Filter System		
Transmit Shock &	Oil Filter System		
Monitor Filter	Oil Filter System		
Prevent Vapor Lea	Oil Filter System		
Prevent Lubricant	Oil Filter System		
Transmit Thermal	Oil Filter System		
Install Filter	Oil Filter System		
Install Filter	Oil Filter System		
Install Filter	Oil Filter System		
Install Filter	Oil Filter System		
Remove Filter	Oil Filter System		
Remove Filter	Oil Filter System		

Table 7: Detail Requirements

Interaction	Role	ID	Requirement Statement
Filter Lubricant	Oil Filter System	OF-50	For a Return Lubricant stream of [Lubricant Viscosity Range] and [Lubricant Pressure Range], the Oil Filter shall separate Filtered Contaminant particles from the Lubricant output stream, according to the [Filter Particle Size Distribution Profile].
Filter Lubricant	Oil Filter System	OF-51	The Oil Filter shall operate at lubricant pressure of [Max Lubricant Pressure] with structural failure rates less than [Max Structural Failure Rate] over an in-service life of [Min Service Life].
Filter Lubricant	Oil Filter System	OF-52	The Oil Filter shall accommodate a Lubricant flow rate of [Lubricant Flow Rate].
Filter Lubricant	Lubricant Distribution Pump	OF-53	The Pump shall maintain oil pressure within the [Lubricant Pressure Range].
Filter Lubricant	Lubricant In	OF-54	The Lubricant in Filtration shall have viscosity within the [Lubricant

Figure 3.7. Comparison of Detail Requirements Table,(Orange represents Document Generated from Integration and Blue represents Document Created by Professional System Engineer)

Figures 3.5 3.6 3.7 show that:

1. The automatic generated tables can provide the same amount of information as the manually created tables. With the proper organization of data, the same numbers of items and their correct properties were extracted automatically from the model implemented in the PLM platform.

2. The automatic generated tables can have very similar format and structure as the manually created tables by configuring the table templates.

These observations proved that the current implementation approach built a model inside the PLM platform that is an accurate representation of the original MBSE model. The implementation is validated.

4. CONCLUSIONS

The processes developed for implementing an MBSE model into a PLM platform and automatic generating requirement tables have proven to be a valid and effective approach based on the findings of this project. The findings from the current implementation are listed below.

1. The general manufacturing model can be configured for a particular product or product line through Specialization.
2. The requirement tables can be generated automatically with proper organization of the data and configuration of the table templates.
3. The implementation in this project can provide the same amount of information through requirement tables as the current systems engineers manual reporting processes.

The approach from this research project set a solid starting point for a long term efforts of integrating MBSE with PLM and leading the industries to eventually reach the goal of implementing SDPD in their product life cycle.

5. FUTURE WORK

Several critical future research issues can be addressed based on the work of this project.

1. The current implementation is a manual implementation, i.e. all the classes, properties and items were created by the researchers. It worked for the current research project, since the goal was to identify the best implementation approach. However, automatic implementation needs to be considered for future industry implementation.

2. The current implementation is build based on the System Engineering module in Siemens Teamcenter. It is a platform specific implementation. A platform independent implementation approach and data model will have much larger impact to this research area and worth more time and efforts in the future. The results from this project built a solid foundation for the future implementation and also provide the research team a great opportunity to have a deeper and more accurate understanding of the problem.

3. The S* model was chosen for this project, so the current implementation is a model specific implementation. Higher level guidelines for model and platform independent implementation approaches should be developed in the future. The research team will look deeper into the fundamental nature of the MBSE models and the implementation approaches to establish general processes, data models and implementation guidelines that can benefit both industry and academia no matter which PLM platform and MBSE model are under consideration.

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