Product Structure Modeling in an Enterprise Resource Planning System

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Abstract

Information systems such as Enterprise Resource Planning (ERP) play an important role in the way companies operate and compete. ERP systems include Product Structure Management (PSM) among their set of crucial modules since it is one of the key processes in a company. However, due to its complexity, the modeling of an efficient PSM component and its integration into ERP systems remain challenging.

With the purpose of defining a suitable product structure model for a target system, Open Operational Platform (O2P), this thesis explores the common features of ERP systems with relevance to product structures. For this, the uses and issues of product structures in manufacturing and ERP are first identified. Then, through a review of examples of modeling approaches in the academic literature, a suitable model is suggested along with its implementation in O2P, in addition to which the findings on the use of product structures in ERP systems are outlined. Finally, the resulting PSM is evaluated based on the predefined needs of O2P.

The thesis concludes that successful integration of PSM into ERP systems require an investigation on the purpose of use of product structures and the characteristics of the ERP system in question.

Key words and terms: ERP systems, Product Structure Management, modeling, manufacturing.
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1. Introduction
Information technologies play an important role in the way companies operate and compete. Information systems offer companies new market opportunities via process integration, reduced response time and ubiquity [Sánchez and Yagüe, 2010]. Enterprise Resource Planning (ERP), Customer Relationship Management (CRM) and Supply Chain Management (SCM) systems can be counted as some of the notable examples of what can be defined as ‘Enterprise Systems’ [Brown and Vessey, 2003]. ERP is a critical information system that manages through the integration, all aspects of a business including production planning, purchasing, manufacturing, sales, distribution and accounting. ERP systems, such as SAP\(^1\), Oracle E-Business Suite\(^2\), are well recognized and considered valuable by many Fortune 500 companies [Poston and Granbski, 2000; Bidarra et al., 2002]. These systems benefit the companies with the automation of business processes and provide operational enhancements in cost reduction, productivity, quality and customer services [Bidarra et al., 2002].

One of the key processes in a company and, as a result, one of the crucial functionalities in an ERP system is Product Structure Management (PSM). The hierarchical classification of materials, component parts, subassemblies and other items making up a product is typically referred to as the product structure [Peng and Trappey 1998; Do et al., 2002]. Throughout manufacturing, the product structure is used intensively by many of the business processes involved. Each of these processes requires different information from the composition of the product structure. To answer these needs, in a product structure breakdown, the type of objects included and the way they relate to each other are dependent on the purpose of product structure’s use for example in engineering or manufacturing [Svensson and Malmqvist, 2000]. In addition to being versatile, the structure of a product is subject to changes at a variety of stages in the manufacturing process. For companies, the product structure is accepted as a key artifact for many their business activities [Svensson and Malmqvist 2000; Ni et al., 2008]. Therefore, companies need efficient systems to keep track of these changes to the product structure and make to make it available for the business processes that need it.

\(^1\) http://www.sap.com/ (accessed 10 November 2011)
PSM aims to integrate the heterogeneous points of view on the product data and the structure as the representation of the product structure evolves according to the different requirements throughout the product lifecycle [Brière-Côté et al., 2010]. In ERP systems, PSM is a common functionality that allows bridging the knowledge about the product with business processes such as capacity planning, logistics, sales order management, production planning and material procurement all of which rely on the product composition data. However, the usages of a product structure breakdown are not restricted to this set of features but rather expand to those of engineering design, order management and services [Svensson and Malmqvist, 2000]. Therefore, defining the features of a product structure in ERP system is not straightforward. On the contrary, the blurry boundary between ERPs and other systems based on the capabilities necessitate the product model and the PSM module to be designed hand in hand with the needs and the capabilities of the ERP system in question. Due to its complexity, modeling and integration of an efficient product structure management component in the ERP systems remain challenging. With the aim of addressing the challenges in order to define a suitable product structure model for a system, Open Operational Platform\(^3\) (O2P), this thesis explores the ERP systems with relevance to product structures.

O2P is a web based platform that offers companies solutions for various business processes including logistics execution, inventory management and warehouse management in addition to other but limited ERP capabilities. A range of clients from frozen food distribution and retail to airplane manufacture companies use O2P to carry out these mostly operational activities. One of the fundamental features of ERP is the materials requirements planning that is used to calculate the requirements in the planning of the production. O2P is therefore planned to expand and include material requirements planning. The pilot environment of this expansion represents one of the customers, CateringPor. CateringPor is an airline catering supplier in Portugal serving meals and providing logistic support for all major airlines operating at Lisbon's international airport [Processware, 2011]. For a better control of the in-house production, it was decided that the central information system, O2P, should be extended to cover relevant features such as production planning and procurement planning which, consequently, created the need for a product structure paradigm.

\(^3\) The main product of Processware Ltd, a company based in Lisbon, Portugal and in São Paulo, Brazil.
With the purpose of defining a suitable product structure model for O2P, this thesis attempts to find answers to the following questions:

- What are the key issues of product structure management in ERP systems?
- How to create a product structure model and a product structure management component in O2P?

In order to tackle these questions, it was important to first review the functions and characteristics of ERP systems. More specifically, modules related to product structure and its management in ERP systems had to be identified and analyzed. Secondly, in order to list the expectations for the prospective PSM functionality, an investigation of the problem domain with its existing modules and needs for a product structure paradigm was conducted. Based on the findings, it was possible to discuss a variety of high level modeling approaches and their applicability to O2P. In the light of these examples presented in research papers, a solution model was built. According to the model, the implementation of the PSM component and the revision of the related modules were made. Consequently, the evaluation and discussion were carried out based on the predefined needs of CateringPor and the platform.

In the next chapter, ERP systems, the concept of product structures and product structure management module are discussed with their significance to manufacturing. After the introduction of the concepts, the target ERP system, O2P, its existing features related to PSM and the needs for a PSM are presented in Chapter 3. In Chapter 4, different uses and examples of modeling approaches of product structures in prior academic works are reviewed. Chapter 5 offers a solution model for O2P and the implementation of a PSM module. The solution is further discussed and evaluated in Chapter 6.
2. ERP Systems and Product Structure Management

2.1 Overview of ERP systems
The way companies operate and compete has been reformed by the rapid changes in information technology. By means of process integration, reduced response time, and ubiquity, information technologies are giving companies new market opportunities. Nowadays, it has become much easier for customers to know about each product or service that is contracted [Sánchez and Yagüe, 2010]. Brown and Vessey [2003] define complex software packages that offer the potential of integrating data and processes across functions in an enterprise as 'Enterprise Systems'. In this category they list ERP, Customer Relationship Management and Supply Chain Management as examples. Despite being complex, these systems have gained favor because they provide centralized solutions for the enterprises hence reducing the number of systems they use [Brown and Vessey, 2003].

The appearance of the adoption of similar systems dates back to 1960s with the first examples of enterprise wide software implementation initiatives [ERP.com, 2011]. As manufacturers moved to Just-in-Time inventory planning, they needed better organization, production planning and sales forecasts and less warehousing. In order to achieve these, a new dynamic system to manage enterprise-wide processes was needed. The early examples were concerned solely with the manufacturing process but in the 1980s, they started to cover areas such as finance, human resource, engineering and project management [Kämpf, 2011]. With these extensions, in the following years ERP presented an opportunity for centralizing units and various business areas. In addition, the year 2000 and the Euro played an important role in ERP adoption decisions on a global scale due of the lack of confidence in legacy systems for changes in the date and currency conversions [Dahlen and Elffson, 1999]. As a result of these factors, the number of ERP implementations in all sizes of businesses and in both the public and private sectors to replace legacy systems rocketed [ERP.com, 2011].

ERP has been defined by Khalid [2002] as “an information system that manages through integration, all aspects of a business including the production planning, purchasing, manufacturing, sales, distribution and accounting”. In another recognized definition ERP is defined as "Comprehensive packaged software solutions that seek to integrate the complete range of business processes and functions in order to present a
holistic view of the business from a single information and IT architecture” [Gable, 1998]. The main characteristics of ERP are listed below.

**ERP is packaged software.** ERP systems are installed as a package consisting of several integrated but separable modules. These modules are closely interrelated but map different business activities to the information system. ERP systems are different from propriety in-house software as they are more standardized. This allows an enterprise to use only a portion of an ERP package rather than the entire software system in order to integrate a selection of its business activities.

**ERP covers the majority of a business’s processes.** The problems ERP systems were able to solve were once restricted to a limited part of businesses. An enterprise system must cover the following three business functions to be considered an ERP: manufacturing, distribution, finance and human resources [Dahlen and Elfsson, 1999]. Today, major ERP vendors such as SAP provide solutions with extensive module sets for enterprises in both specific and cross-industry environments.

**ERP changes/redefines the company’s business processes.** In the past, the companies would either develop an in-house system or choose and purchase a software package that would require rewriting large portions of the software to ensure a tight fit. ERP systems reversed this sequence by forcing the business processes to fit the system. Since the systems are modular, companies can limit the installation with modules that are most appropriate in addition to a certain degree of customization. However, due to the complexity of the system, major modifications are basically impractical and necessitate changes in the business processes [Dahlen and Elfsson, 1999]. Moreover, ERP systems reflect their vendors’ understanding of best practices in each of their client’s business processes [Monk and Wagner, 2006]. The existing need to reengineer the business processes to match the dictates of the software drives companies to take this opportunity to revise their processes even beyond the ERP requirements [Rathinakumar, 2000].

Enterprises have greatly benefited from ERP systems. To begin with, in the past, in huge enterprises, considering the fact that all of the business units had their own computers, databases and reporting systems, it was a tremendous task to produce company-wide forecasts, prepare budgets and tie numbers monthly, quarterly and annually [ERP.com, 2011]. In addition to information retrieval, the maintenance of this
vast information which is spread across large amount of computer systems is very costly [Dahlen and Elfsson, 1999]. Another important point is the indirect costs of the lack of a centralized system and real-time information access across the enterprise. A company’s customer responsiveness and manufacturing productivity would suffer if its sales and ordering systems could not communicate with the production system. The management would have to make decisions based on instincts rather than according to a detailed understanding of product and customer profitability if the finance department could not effectively communicate with the sales and marketing systems [Dahlen and Elfsson, 1999]. ERP systems can be defined as software systems that help enterprises solve these issues. Enterprise resource planning systems are a major adoption of information technology that has reformed the companies’ management principles and structures [Sánchez and Yagüe, 2010].

Additionally, a study by Poston and Granbski [2000] found that the tangible benefits of ERP included a reduction of costs and an enhancement in decision making due to the ease of access to enterprise-wide information. ERP can provide a strategic solution for the future of companies by giving them the opportunity to rationalize and develop their organization through better control of the company’s information flow [Dahlen and Elfsson, 1999].

Furthermore, ERP integration can help organizations achieve strategic benefits by supporting business growth and alliances, building business innovation and reducing costs. In addition to business and strategic benefits, ERP offers organizational gains by supporting organizational barriers, facilitating business learning, promoting empowerment and building common visions [Sánchez and Yagüe, 2010]. The transparency, use of analytics and ease of access to company wide information are considered important for improving productivity and insight among the employees [SAP, 2011]. For many companies, the adoption of ERP systems made legacy systems outdated and obsolete and decreased the amount of total systems [Bae and Ashcroft, 2004]. The simplification of systems is reflected in business productivity as well as a more flexible IT infrastructure [Sánchez and Yagüe, 2010]. Last but not least, this reduction of total systems into a single system not only reduces maintenance costs but also decreases the dependence on a few key users [Dahlen and Elfsson, 1999].
2.1.2 Modules and Functional Areas

Davenport [1998] presents a reference model for ERP systems, as shown in the figure.

![Figure 1-The Structure of ERP systems [Davenport, 1998]](image)

The companies that adapt ERP selectively use the modules presented to integrate their business activities in manufacturing, distribution, finance and human resources. In Figure 1, the modules to the right are usually used by “Back-office administrators and workers” that provide the necessary interface with “Suppliers” in manufacturing. Similarly, certain modules benefit “Sales force and customer service representatives” who support the distribution of products and services to the “Customers”. In the center of all the processes, the use of a database enables streamlining of the company information that is transferred throughout a business [Dahlen and Elfsson, 1999]. The modules presented above can be further explained as below.

- **Financial Applications** stand as one of the main modules and deals with the accounting and financial data around the departments of the company and reporting general ledger and trial balance and so on.
• **Service applications** help in providing customers with the company’s services that can be exposed via information systems such as providing analysis or forecast information that is of use for customers.

• **Human Resource Management Applications** are used for management of human resources and human capital in the enterprise. This module is used for maintaining the information related to the personnel such as personal contact details, salary details, attendance and performance as well as payments.

• **The Sales and Delivery Applications** module supports the company in many activities of the sales and marketing processes such as order placement, order scheduling, shipping and invoicing of clients as well as in the related data management of clients, competitors, forecasting and reporting.

• **Reporting Applications** provide the company an insight on making decisions or improving processes by means of information extraction from the internal and external businesses of the company.

• **The Inventory and Supply Applications** module optimizes the stock in a warehouse of an enterprise. Identifying required materials, replenishment management, item usage monitoring and reporting are activities included in this module. Capabilities of this module can extend to cover supply chain management processes.

• **Manufacturing Applications** form a rather extensive list of business processes and are covered with a range of modules in different scenarios. This module is responsible for diverse aspects and stages of the production process with sub-modules such as logistics, production planning and control, procurement and materials management. In addition, it can include components such as product lifecycle management which are not necessarily concerned with certain stages but with particular aspects of the overall manufacturing.

It must be noted that this is an extensive list and some of these modules are mutually replaceable or can be included within another module depending on the business needs. For example, SAP R/3 groups materials management and sales & distribution under a logistics module whereas in the Oracle Business suite marketing and sales module stands as distinct from logistics. Also notably, manufacturing applications are grouped under supply chain management module in Oracle while manufacturing related functions are mostly enclosed in production planning [SAP, 2011; Oracle, 2011]. It is necessary to keep in mind that modules in ERP are closely
interrelated and their functionalities span their modular borders due to the nature of ERP.

Depending on its purpose, product structure management may reside in the manufacturing branch of common ERP modules as a part of the product lifecycle management (PLM) as in SAP R/3. PLM manages the detailed information that engineers need to carry out the design using part specifications, design and test artifacts and vendor supplied documentation in addition to other exhaustive features [Backbones, 2008]. PLM has gained more importance over the last years and urged the manufacturers to try tracking product information across the full life cycle by means of integrating PLM within their existing ERP [Jackson and Houlihan, 2008]. It is agreed that this integration delivers significant benefits for companies of all sizes [CIMdata, 2011; Edelhauser and Buse, 2008; Brown, 2004]. However due to its inherent purpose and focus on manufacturing, not all ERP systems include PLM features. In such cases, PSM may still be needed for other processes such as procurement and purchase planning. The following section explains product structure management and related modules further in detail.

2.2 Product Structure Management in ERP systems

2.2.1 Product Structure and Master Data
In ERP systems, product structure management is a common transaction to create and maintain the structures describing the product that is needed for manufacturing. PSM allows bridging the knowledge about the product with business processes such as capacity planning, logistics, sales order management, production planning and material procurement. These business processes form the core of manufacturing functionality in ERP and heavily rely on the data on the product composition.

In manufacturing, the main source on the product composition is the product structure which is typically defined as a hierarchical classification of materials, component parts, subassemblies and other items making up a product [Peng and Trappey 1998; Do et al., 2002]. A product structure example is shown below in Figure 2.
When representing a structural aspect of a product, the composition of objects and their relationships are defined for a particular purpose. Likewise, it is this purpose that determines the type of objects that comprise the product structure and how they relate to each other [Svensson and Malmqvist, 2000]. Figure 3 represents two product structures built for sales and purchasing purposes. It is worth noting that certain attributes of a car that would interest buyers are chosen for the sales view whereas components that would be used in manufacturing or configuration are of interest for purchasing purposes.

Therefore, product structure, as an artifact, is versatile and multi-faceted, depending on its purpose of use such as engineering or manufacturing.

In IT systems, the product structure is strongly related with the master data which is commonly described as the persistent, non-transactional data about customers, suppliers, partners, products, materials, accounts and other critical “entities” [IBM, 2011]. Figure 4 shows a set of as master data record samples for various entities namely “Customer”, “Product”, “Product Container” and “Location”.

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**Figure 2** - A Product Structure breakdown of a car [Wikipedia, 2011]

**Figure 3** - A Product Structure breakdown of a car [Wikipedia, 2011]
Master data is normally stored and replicated across IT systems and is used to support critical business processes across the enterprise. For most enterprises, regardless of their use of ERP, this master data related to the above mentioned exhaustive list of entities, is used heavily and is at the heart of every business transaction, application, report and decision. Therefore this data needs to be up-to-date, accurate, complete and consistent. Among the above mentioned entities, two concepts are closely related to the product structure: Material Masters and Bill of Materials.

Material Masters are considered the core functionality for any ERP system that supports an enterprise both in the distribution of the product and in the manufacturing related processes. They constitute the central repository of all the materials that the company uses from procurement and production to inventory. For instance in SAP R/3, the material master contains all data for parts, products, semi-finished products, raw materials, auxiliary structures, supplies, production sources/tools, and other types of materials [SAP, 2011].

Another type of master data is the bill of materials (BOM) which is simply given as a list of materials including their quantities needed to make an assembly, part or a product [Monk and Wagner, 2008]. In ERP systems, such as SAP R/3, the master data that BOM constitutes is essential for materials management and production control. Additionally, for production planning, BOM data serves as a basis for various activities as it provides information on the list of materials and quantities. For example, in materials requirements planning BOMs are used for calculating cost-effective order quantities for materials, or in production planning and control, BOM data is used for planning the provision of materials.

Brière-Côté et al. [2010] shed some light on a common debate over the ambiguity of the definitions of product structure and BOM. In BOMs the materials also refer to

<table>
<thead>
<tr>
<th>Master Data Object</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer</td>
<td>David Loshin</td>
</tr>
<tr>
<td>Product</td>
<td>Seat 150</td>
</tr>
<tr>
<td>Product container</td>
<td>Flight 238</td>
</tr>
<tr>
<td>Location</td>
<td>San Francisco</td>
</tr>
</tbody>
</table>

Figure 4- Master data on various entities [Loshin, 2008]
components, parts, subassemblies and raw material and the thorough list of these materials with their required quantities makes up the BOM [Sääksvuori and Immonen, 2005; Brière-Côté et al., 2010]. This description is similar to the concept of product structure. The given information about a product is fundamentally the same in a BOM as well as in a product structure. However, from the configuration management point of view, BOMs are not the same as the product structures because product structures provide flexibility with variant materials and options for subassembly selections. Moreover, the definition of product structure is more comprehensive due to the fact that the forming set of objects and their relationships must have a particular purpose [Brière-Côté et al., 2010]. Especially, from the PLM perspective, when modeling the product structure, the range of business functions and the actors involved in different processes must be considered and the item oriented approach of BOMs might not suffice [Brière-Côté et al., 2010].

Product structure is used as a master data in common modules and individual transactions such as materials management, BOM management, production and procurement planning as well as purchase planning in addition to others regarding sales, marketing and logistics. In the activities related to these transactions, the product structure is used as the simplest data that is needed for these processes to be carried out. In the next section, PSM related modules are discussed more in detail.

2.2.2 Related Modules and Importance
Keeping the lack of standardization among the vendors in mind and considering the similarities, the common ERP modules that are directly related to product structure management can be outlined as below.

Production planning and control module is used to realize the product planning based on quantity and time in addition to the controlling of the production process as a whole. This module supports all quantity-based and capacity-based production planning and control production steps besides master-data maintenance functions. In the process of Production planning, the activities below are included [SAP, 2011].

- **Sales and Operations Planning** is carried out for determining the quantities to be produced. This process does not necessarily consider the stocks and available capacities but in effect, it defines the future requirements that are decided more clearly later in Demand Management.
• **Demand Management** is used to compare sales planning output with the customer requirements to define the independent requirements for production.

• **Material Requirements Planning** is used to calculate net requirements and component requirements taking into account lead times, scrap quantities and lot sizes. This can be considered as the central function of production planning.

• **Capacity Requirements Planning** is used for determining available capacities.

• **Production Control** helps controlling and recording the production process via production documents, record confirmations.

• **Production Order Creation, Production Order Execution** are used to control and record the production from material withdrawal in addition to order confirmation for storage and invoicing.

• **Capacity Planning** schedules the processes for created and released production orders and delivers a production sequence that is feasible from the capacity point of view.

• **Production Execution** is concerned with the recording and controlling of the production process from material withdrawal to order confirmation to storage and invoicing as specified in the production order.

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![Production Planning Overview](SAP, 2011)

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**Figure 5 - Production Planning Overview [SAP, 2011]**
Figure 5 represents the activities of production planning and their interrelations with each other. Product structure as master data is used as a major artifact in some of the aforementioned processes directly and therefore affecting the rest of the process chain. Above all, “Material Requirements Planning” step relies heavily on the composition of parts as it turns the high level demands of the customers to a detailed list of materials by *explosion*\(^4\) the product’s structure for the target quantities. Similarly during “Capacity Requirements Planning” and “Production Execution”, the interdependency between input and output of materials, bi-products, parts for their quantities is controlled. Therefore, product structure is directly related to these transactions and a critical artifact for the entire chain.

**Materials Management / Procurement Logistics** module is used for procurement, inventory and warehouse operations in daily business operations such as purchasing, inventory management and reorder point processing. It is normally interrelated with other modules such as sales and distribution, production planning and quality management. It consists of the necessary master data management, system configurations and transactions to complete the procurement of goods for production. Materials management is highly connected with other modules and with functions such as consumption based planning, planning, vendor evaluation, and invoice verification. It supports a list of comprehensive supply chain management tasks. To understand the extent of materials management, the aforementioned functions can be explained further in detail as follows [SAP-ERP, 2011]:

- **Consumption Based Planning** is used for the control stock replenishment, determining lot sizing procedures and forecasting.
- **Purchasing** helps determine the possible supply sources, procurement, delivery tracking, monitor vendor payments.
- **Inventory Management** is used for materials records, tracking of good movements, physical inventory and stock determination and batch handling

\(^4\) *Explosion* is a term used for determining the final quantities when the items are used in groups or packing containers by simply multiplying the container quantity with the quantity that of the item per container.
• *Invoice Verification* is used for supporting verification and material valuations, managing changes in credits, taxes, cash discounts
• *External Services Planning* supports external service procurement, bidding, invitation, acceptance of the procured services in addition to follow up verification and billing processes.

It is worth noting that the overlapping definitions and unclear borderlines between the functionalities of modules and transactions are the nature of ERP systems. The reason of this close interconnection is the internal flow of documents, integrated data retention and the functional integration of the software [ERPChronicle, 2011].

To sum up, product structure management is a critical activity and plays an important role in the ERP system and hence in the manufacturing process. An efficient PSM is able to shorten the development process and helps companies cut down on costs and increase product quality [GopaIT, 2011]. Since the efficiency of PSM transaction is inherently dependent on the product structure modeling, to address the need for product structure management in ERP systems, suitable product structure modeling techniques must be investigated.
3. Product Structure Management in Open Operational Platform

3.1 Open Operational Platform

Open Operational Platform (O2P) is the main product of Processware Ltd, a company based in Lisbon, Portugal and in São Paulo, Brazil [Processware, 2011]. It is a web based platform that offers solution to companies in various business areas including manufacturing, services and industrial goods. O2P is used to support diverse business activities such as frozen food distribution, retail and airplane manufacture. Recently, it has been progressively extended to carry the features of a common ERP with logistics execution, inventory management and warehouse management in addition to the most recent addition in the capabilities of production planning which is the main concern of this research.

While in some implementations, the functions of O2P are integrated into the corporate ERP and restricted to the optimization of certain business processes, in others O2P resembles ERP systems in the conventional sense and is widely used across the enterprise as the central information system. Typically, the latter case is the main reason for the continuous development of O2P towards an ERP as it as requires a comprehensive list of transactions in order to offer a more integrated solution.

On the other hand, O2P differs from the conventional ERP systems in certain ways. Despite the common characteristics and functionality, the target environment or the business line of ERP systems may vary. For instance, SAP R/3 supports organizations in four business areas: human resources, financial, supply chain management and marketing [Bae and Ashcroft 2004]. Therefore SAP R/3 is more suitable for companies whose main business processes are included in these business areas. Likewise, O2P differs from other ERP systems in this aspect due to its focus in operational activities of manufacturing. Unlike SAP R/3, O2P does not integrate PLM capabilities. As a result, O2P is not suitable for companies with needs for engineering and design activities based on part specifications, design and test artifacts and vendor supplied documentation. The significance of such difference comes with major implications on the process of the product structure modeling. This chapter will introduce the target platform and its motivation for a product structure model.
3.2 Material and BOM Master Data Management in O2P

The early and core features of O2P supported operational processes such as goods receipt, goods movement, goods issue, inventory and material handling, picking and packing, transport management, and shipping container preparation. These transactions necessitate the existence of certain master data around materials, BOMs, customers, vendors, plant definition and so on. At this state the organization of this master data already supports certain extensive features to describe products, components and parts with the material and BOM management.

The management of material masters in O2P follows the example of SAP R/3 in which the material master contains all data for parts, products, semi-finished products, raw materials, auxiliary structures, supplies, production sources/tools, and other types of material [SAP, 2011]. The attributes of materials such as material number, descriptions in various languages, weight and basic classification data are used to differentiate between materials and realize categorization for reuse. In O2P, material masters are associated with a number of other entities to reduce duplication. As a very simple example, a material master in the material management transaction of O2P is presented in Figure 6.
Figure 6 shows various properties of material masters from their unique identifier, i.e. “Material Code”, to the dimensions and the storage-related attributes and also operation specific and categorizing properties such as “Support Type”, “Service Class,” “Service Type”, “Options Type”, “Equipment Type”. Materials can have additional information for the appropriate contexts using other sub-entities. For example, each Material object can have a MaterialPlant object (as shown in Figure 7, these materials are managed in the tabs “Descriptions”, “Customers”, “Vendors”) for further customization. For example, the tax values that are applied to a material can vary at a different plant (location). Similarly a version for a material can be defined so the material would behave differently at different dates. Material masters in O2P cannot be broken into other objects but using different attributes they allow flexibility and reuse.
In SAP R/3 and other packages that support PLM, BOMs are treated as an interface between core ERP capabilities of manufacturing and engineering processes. In O2P, however, BOMs are not artifacts of any design or engineering process. Instead, they simply provide the common information for its components such as quantity for each component, the quantities that are wasted in the production process (scrap) and quantity type. BOMs are defined per plant and unit (location under each plant) and can contain basic and rigid cost information in the cases where components have easily defined costs for a long period of time. A material is represented in the BOM as a BOMItem which has common properties with the material it is linked with. By changing BOMItem properties, certain attributes of the material can be overridden at this level. For example, by default a material can have a description such as “Drinking water in 0,5 cl bottle” but it can be overridden to “Default refreshing drink” when used in a BOM that describes a meal. This allows the reuse of the materials and provides extra flexibility in creating variance without the manipulation of actual material data. Below is an extract of the BOM Management in O2P.
Figure 7 - Bill of Materials (BOM) Management

Figure 7 represents a BOM with basic descriptive and classification information in addition to the BOMItems details in the repeaters. This BOM has five items that wrap different materials with respective quantities and unit of measures. Before the introduction of the product structures in O2P, BOMs and materials could have one-to-
many relationship defined using BOMAssignment (see the tab in Figure 7). This means certain materials could be described using BOMs, although this approach lacks the flexibility that is needed for certain processes.
Figure 8 - Relationship of BOM and Material Classes

Figure 8 represents the relationship of BOM and material related classes. As explained before, every BOMItem is associated with only one material. Multiple BOMItems are used to form a BOM (BOMHeader class). This BOM can be used as a simple breakdown of a Material using the associations created via BOMAssignment class.

The next example can be given to further explain how BOM and material masters are used in certain processes that do not require a more complex entity such as the product data. The following scenario explains the inventory process that is carried out in Jeronimo Martins, an international supermarket chain that uses O2P to keep track of the stocks in their stores [Processware, 2011].

Weekly inventory documents with materials that are supposed to exist in the store are created and distributed to the stores. The Inventory document includes the list of materials that are supposed to exist in the shelves but do not specify their quantities. A store operator reads the barcode of an item in the shelves via mobile terminals and O2P processes the barcode.

- If the item is found in the Inventory document’s items list, the operator adds the actual quantities found to the document.
- If the item is not listed in the document, O2P checks if there is any BOM that is assigned to that particular item. If there exists a BOM, this time O2P looks for the BOMItems in the inventory document list and for each item and updates the document with the quantities based on the BOM quantity explosion.

Later, as the operator continues reading the barcodes of the items in the store, if an item that was already encountered as a BOMItem is found elsewhere in the store, the quantity is added to the previous sum. At the end of the process, the updated inventory document is sent back to the system for cross-checking the quantities that exist in the store and in the database.

![Inventory Document (before)](image1)

<table>
<thead>
<tr>
<th>Items</th>
<th>Qty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twix 160G</td>
<td>?</td>
</tr>
<tr>
<td>M&amp;M 160G</td>
<td>?</td>
</tr>
<tr>
<td>Twix 148G</td>
<td>?</td>
</tr>
<tr>
<td>M&amp;M 148G</td>
<td>?</td>
</tr>
</tbody>
</table>

![Inventory Document (after)](image2)

<table>
<thead>
<tr>
<th>Items</th>
<th>Qty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twix 160G</td>
<td>890 units</td>
</tr>
<tr>
<td>M&amp;M 160G</td>
<td>640 units</td>
</tr>
<tr>
<td>Twix 148G</td>
<td>320 units</td>
</tr>
<tr>
<td>M&amp;M 148G</td>
<td>320 units</td>
</tr>
</tbody>
</table>

Figure 9 - Inventory example at a supermarket store

Figure 9 shows an example where an inventory process is carried out for chocolate bars.
3.3 The Need for a Product Structure Management in O2P

The need for a product structure mechanism appeared due to the prospective addition of material requirements planning related features such as production planning and procurement planning to O2P. The pilot environment was one of the customers, CateringPor which is an airline catering supplier in Portugal serving meals and providing logistic support for all major airlines operating at Lisbon's international airport [Processware, 2011]. O2P has been the central information system in this enterprise covering a multitude of their business activities especially in operatory levels such as flight preparation and loading processes. Later on, in order to answer the emerging needs for a better control of the in-house production, it was decided that O2P should be extended to cover relevant features such as production and procurement planning. These modules aimed to support the end-to-end activities of in-house production in CateringPor. A simple scenario to explain these activities could be as follows.

*CateringPor defines a new hot lunch for long haul flights and adds it to its product list. This new product has many commonalities with many previous menus but it had to be specifically tailored for the new customer, USAirways. The contents of the new menu is thoroughly defined including material requirements with quantities, product categorization and cost values. The proposal for the new product is sent to the customer, along with the pricing details based on the cost and various customer related factors such as applied taxes. Upon agreement, CateringPor initiates the procurement of required materials based on the medium to long-term needs. Production plan is carried out and the customer is delivered. The new hot lunch is added to the list of meal types on USAirways flights from Lisbon. The customer is billed and invoiced based on the previous pricing agreement.*

Although the invoice management and the loading of flight meals were already handled via O2P, the existing level of detail and the organization of the concepts were insufficient for a full circle of complex business activities such as production planning and procurement planning.

In the activities of production planning, the composition of the product gains vital importance. In order to be able to control the production process, the hierarchical breakdown of the components into others and their relationships must be known. The
existing concepts of material and BOM allowed the hierarchical relationship to a certain extent. Because the BOM is a list of materials and the end result of this composition can be another material. This means a BOM could be used to represent the breakdown of a material. However, in the reality of manufacturing where dates, locations, small customizations and customers affect the product, there would be need for a matching material and a BOM and consequently this one-to-one matching would result in massive duplication of data. Much like other manufacturers, in defining their products, the catering companies need to deal with immense amount of data. Especially when food materials are considered, keeping track of the composition of flight menus in detail is highly complicated. In order to be able to manage these constantly changing and volatile products, CateringPor needs to keep track of the material quantities, requirements and cost values in an efficient way.

Similarly, supporting the **product variety** is a challenge in manufacturing. Now, it is critical for companies to realize variety in their end products in an increasingly efficient and cost effective manner. Also, CateringPor deals with a number of airlines as customers and they need good support in flight menu variance. It is in the very nature of their business to derive new products by making minor changes to suit their customers’ needs. In O2P, a way to derive new materials by making changes to the composition of another material did not exist.

**The cost and pricing information** is crucial in purchase and production planning. In manufacturing, defining the cost or sale price of a material or BOM is not a straightforward task and depends on many factors such as supply type (in house production or external), the date, quantity, the plant that is doing the purchase or the sales as well as the interested departments and so forth. For CateringPor the cost information is very volatile due to the nature of the business but at the same time it is very important to be able to define cost information conveniently. The existing BOM and material management functionality was not flexible enough to support such pricing information.

In order to answer these needs, a product structure concept was necessary in O2P that would aid CateringPor.

**3.4 Major features for PSM capabilities in O2P**

Although CateringPor has been the main problem domain, in the development of O2P flexibility is valued so that its features are generic enough to fit other customer cases in
the future. Therefore it is important to distinguish between O2P and CateringPor specific issues as well as from others of common ERP.

**Versioning**

The factors that alter the ingredients or the pricing of a material must be defined. Consider the following example:

*Rice pudding, a dessert, is made of rice, milk, cinnamon and raisins. 'Rice pudding A' as the product can include soy milk at a production plant in Mumbai and dairy milk in London. Or from a pre-defined date on, 'RiceBrandA' might be started to be used in production instead of 'RiceBrandB' which happens to be cheaper. Or 'CustomerA' may not want raisins in their rice puddings.*

All these factors change the end product in someway. Nevertheless the product might be referred to as the same in the system. Based on this simple example, the trivial answers to this versioning problem could be counted as the date, the customer and the plant information. However, CateringPor specific aspects of this problem must be solved as well.

**Material Classification**

Obviously not all materials can be described and represented in a hierarchical manner. For example, product structure may not be necessary for raw materials or materials which are not in-house manufactured. These types should be decided. For the suiting ones, PSM should allow for the creation of product structures that serve as the main artifact to describe all versions of these materials.

**Reusability**

The data multiplication should be minimized while creating structures and mapping them to material masters that describe end products, in the case of CaterinPor, the flight meals. Due to the nature of the business, the variance in meal types is a big asset. The abundance of options can easily be realized by altering the ingredients and production processes of a meal. The downside is that without adequate data models, the duplication of data would increase rapidly. Therefore, product structures in O2P should be flexible and allow reuse.
Different Views for Costing

There should be a way to determine the cost and sale price information of materials to be used in relevant business operations such as purchase, sales and billing. There should be defined rules in the calculation, the presentation of this information and its availability for a given material. For example, the cost information of a product should be able to be calculated in different aspects such as for internal accounting or for sales.

BOM vs. Product Structure

The definition of BOM should be extended to support a consistent relationship with product structure. BOMs in O2P mainly describe the list of materials with their quantity information. In addition to this common approach, the question of whether or not BOMs and product structures should have different views such as engineering view as an alternative to manufacturing view should be discussed.
4. Towards Product Structure Modeling

Firms have had to improve their major processes to increase productivity and remain competitive. In terms of process improvement, the manufacturing process is naturally the main concern for the production firms [Svensson and Malmqvist, 2000]. For these manufacturers, product structure, which is a hierarchical decomposition of the end product, is accepted as a key artifact for many business activities and at a variety of stages in the manufacturing process [Svensson and Malmqvist 2000; Ni et al., 2008]. Therefore, the modeling of product structure is directly related to the success of the company.

4.1 Product Structure as a Model

In the design and the development of a product structure management module, we need to define the necessary attributes of a product to present. Additionally, the rules through which the users of the system will interact with the structure must be clarified. This scoping of the master data and the creation of rules are realized with a model. Models are used to map the real world to an alternative representation that is usually less complex and practically useful in certain ways. In essence, this mapping, reduction in properties and pragmatic use are considered the three main criteria for a model [Ludewig, 2003].

Models are a big part of information technology, in particular software engineering which include some examples of models [Ludewig, 2003], such as:

- Process models such as Cleanroom Development or Extreme Programming
- Information flow models such as diagrams used in SADT
- Design models such as class diagrams
- Models of user interaction such as use cases
- Models of principles used for constructional details such as design patterns;
- Process maturity models such as CMM or SPICE.

Furthermore, software engineering itself essentially models the real world in many cases. Since the invention of the computers, systems have been designed to do tasks that mirror real world scenarios for us. By capturing real world events and states,
information systems provide efficient and easy access to this information about the world later at convenience [Jackson, 1995].

By definition, a representation of product structure is a descriptive model that represents the original (mapping criterion); that does not necessarily contain all the possible specifics of a product (therefore more simple); that is used exhaustively in many other processes of manufacturing (usefulness criterion). The management of product structures is a real world process which can be mapped to software with an appropriate model.

4.2 Different Product Structures
It is almost impossible to develop a satisfactory product structure model by taking into consideration all the requirements of different business processes [Ni et al., 2008]. In reality, however, a product structure model has to be specifically designed for its purpose of use.

The hierarchical breakdown of a product is naturally a crucial artifact not only in the development and the design of the product but for a multitude of business processes. Svensson and Malmqvist [2000] conducted a case study and addressed how different disciplines and users need product structures for different objectives which define product structure’s purpose of composition by imposing different requirements on it. The disciplines and their respective requirements on the product structures are explained below.

**Design:** From the designer point of view, a functionality oriented breakdown of a product to its systems and subsystems is needed. The authors’ findings suggest the users may even need special structures for themselves to indentify, for instance, the parts that are used in a calculation or simulation. In the example below, the common parts of a bicycle are group based on their relationship in functionality.

![Diagram of Bicycle Product Structure](image-url)

Figure 10 - Product Structure for Design [Sääksvuori and Immonen, 2005]
Manufacturing: The users involved in the manufacturing process are interested in the assembly structure. The materials and operations making up the finished product are most important, therefore the design approach of dividing the product into systems and subsystems is not well suited with their needs. In the processes that interface design and manufacturing, as the authors put it, a change in the product structure model is necessary. In the example below, the grouping of the parts are based on the commonalities in the manufacturing order and on a part-of relationship in terms of assemblies as opposed to the functionality oriented design breakdown.

![Diagram of Product Structure for Manufacturing](image)

Purchasing: Due to their needs for forecasting in order to estimate the required quantities and having a control over which products are produced in each manufacturing plant, the purchasers make use of product structure breakdowns which are more similar to those of manufacturing rather than engineering [Sääksvuori and Immonen, 2005].

Sales: The product specification is of more importance consequently making design product structure rather relevant for the activities of sales [Sääksvuori and Immonen, 2005].

Additionally, other specific product structure breakdowns for different business activities such as forecasting and defining spare parts can be necessary depending on the scale, the strategy and the organization of an enterprise.

In ERP systems, the inclusion of functionality oriented design structure in the product structure depends on the existence of PLM functionalities. Most ERP systems today support engineering and design activities of production via PLM module integration. However, the inherent concern of ERP is the improvement of
manufacturing processes as a whole. Therefore there is a need for product structures in ERP to be comprehensive but with a focus on manufacturing.

In a production environment that relies on the engineering and design activities, the design product structure is highly important. Svenson and Malmqvist [2000] identify design structure as the key product structure in such enterprises and refer to it as the “master structure” within the company. In this particular example the company is a car manufacturer where this master structure is the most important source for part data. This necessitates it to be accessible for and used heavily by most parties. The other product structures around the information system rely on this design structure for updates. Therefore in the ERP system PSM must be capable of bridging engineering, manufacturing and other existing product structures when necessary.

In O2P, there is a significant distinction point that shapes its requirements for a product structure paradigm. The extension of O2P platform towards capabilities such as production planning is more aligned with manufacturing purposes than of engineering. The modules that are on hand in O2P also do not require any integration with engineering activities. Furthermore, the nature of the pilot environment, CateringPor, does not necessitate the existence of heavy weight design artifacts related to their product in any of their processes. Due to these reasons, PSM in O2P does not aim to take PLM integration in consideration but focus on manufacturing purposes instead. As a result, among the existing approaches for product structure modeling, the ones that suit for the manufacturing purposes should be considered, although there are more than a few established modeling options that are design and engineering oriented.

4.3 Product Structure Modeling Approaches

4.3.1 Master Structure with Different Views
To satisfy the requirements of different business lines over the product structure breakdown, a simplistic approach exists that supports multiple views of a single product structure. In this context, views are necessarily product structures that are built for different purposes [Van den Hamer and Lepoeter, 1996; Svenson and Malmqvist, 2000; Briere Cote et al., 2010] similar to the examples in section 4.1.2. Clettus [1995] suggested the master structure with multiple views can be achieved by using a single and “complete” structure meanwhile different views display portions of this structure by
filtering out unwanted data. This scenario is exemplified in Figure 12 where each object has properties that can be grouped easily based on the relevance with a certain view.

![Figure 12 - Product Structure with Different Views](image)

However, it is argued that there can be structure breakdowns of a product which cannot be created with filters from any single master structure [Peltonen, 2000; Van den Hamer and Lepoeter, 1996]. To overcome this and take this approach further, *equivalency* mechanisms were used to create *non-isomorphic* hierarchies model [Van den Hamer and Lepoeter, 1996]. The isomorphic product structure model can be achieved when all the views can agree and connect on common product decomposition. But in the latter case, the equivalences would explain how particular components relate with each other in different views [Peltonen, 2000; Briere Cote et al., 2010].

![Figure 13 – Non-isomorphic hierarchies model](image)
Figure 13 is an example of a non-isomorphic scenario where in different views, the objects can be grouped differently and fall on different levels of the structure tree. The equivalence relationships are used to justify this difference.

4.3.2 Generic Product Structure

As a way to manage product variety better, Erens and Verhulst [1997] introduced the concept of Generic Product Structure (GPS) Modeling. Their aim was to aid manufacturers in tackling the difficulties of the buyers’ market that replaced the old manufacturers' market which stressed the importance of suitng customers’ needs. To achieve this, manufacturers started offering more variety in their products and needed better management of the variant commonalities in order to reduce development efforts and lower costs.

Figure 14 shows an example of numerous options for crew seats in a commercial aircraft. The number of the compound variants (on the top level) increase as they form a set of combinations based on two more generic first level variants. The inverse proportion between variance level (hence commonality) and complexity is clear.

---

**Figure 14 - Crew seat variety in a business aircraft [adapted from Briere Cote et al., 2010]**

By aggregating the multilevel description of large sets of variants into a single product structure model, Generic Product Structure modeling simplifies them in a way that is non-redundant [Briere Cote et al., 2010].
Using a part-of hierarchy, GPS describes a product’s generic modules and their organization. It categorizes the components of the model with concepts such as optional, alternative and parametric. The GPS utilizes the semantics of generalization via type-of relationships between the generic modules (types) and variants (instances). This helps address the problem of part selection for highly variable designs. The GPS approach aims to eliminate the need to deal with every variant’s product structure, while managing product variety [Briere Cote et al., 2010].

4.3.3 Master-Variant Pattern
Similar approaches for managing product families have been proposed. These try to reduce the exhaustingly detailed representation of specific products and centralize the modeling.

Du et al. [2000] argue that the understanding of a family of products depends on different perspectives. For sales, the factors when differentiating between variants can be listed as the functional features, options and selection constraints whereas from an engineering perspective, product technologies, structural relationships, and constituent modules can create variants. Based on this argument the authors provide a product
structure model which supports the three different views: functional view, technical view and structural view. Conversely, Janitza et al. [2003] suggest a mass customization product model that combines product decomposition and specifications of part characteristics into a single model. By doing so, they provide simpler configuration for the customer and more flexible product model specification for the product designer. Ni et al. [2008] adapt this approach and improve the product family and variant representations. They utilize a Master-Variant Pattern to build the product structure model that explicitly represents common characteristics and specific features of individual variants.

Here the IMVLink interface bridges masters and variants by exposing the common properties and behavior of associations. The advantage of this approach and the use of this pattern is that it supports business processes with multiple product views in addition to enforcing the consistency of a family structure and its variant structure [Ni et al., 2008].

Figure 16 - Master-Variant Pattern [Ni et al., 2008]
Figure 17 - Product Structure model based on the Master-Variant Pattern [adapted from Ni et al., 2008]

Figure 17 represents the product structure model that uses three groups of classes.

- Products with classes Product, ProductVariant, ProductMVLink,
- Parts with classes Part, PartVariant, PartMVLink,
- Subassemblies with Subassembly, SubassemblyVariant, SubassemblyMVLink.

*Product, Part, and Subassembly classes represent product families, part families and subassembly families while ProductVariant, PartVariant, and SubassemblyVariant represent product variants, part variants and subassembly variants.*
4.3.4 Considerations of Product Structure Models for O2P

For O2P, some of these approaches present a good opportunity for product generalization. The core aspect of GPS modeling in particular is suitable in applying it to the product structures in O2P and the problem domain in question. However, the formation of secondary variants is not applicable to the meal types since it is not a requirement for the solution model. In the creation of meal types, *part-of* relationships can occur but commonly at a high level. For example, a “main dish” and “dessert” types are usually included in the meals. But since this categorization is rather generic, imposing the restrictions of this model is not practical for this problem domain.

Cleetus’s single master structure and multiple views creation via filtering approach is already considered impractical for certain real world scenarios where this *level-by-level* model based on simple *part-of* relationship is not feasible [Peltonen, 2000; Van den Hamer and Lepoeter, 1996]. In contrast, a non-isomorphic model with well-defined equivalency relationships could help achieve a model with different views. However, this approach is also no silver bullet and a new discussion on how to set the equivalencies arises [Briere Cote et al., 2010]. At the end, these approaches may seem fitting for an exhaustive PLM practice but be considered too heavy-weight for the case of O2P.

Finally, having strict rules to form product families, as seen in the master-variant pattern approach, is not very profitable due to the nature of the food industry. Creating recipes in a flexible manner is more important than creating tight relations between products that belong to the same classification or a family. In most cases, the common behaviors between different meal types are hard to identify or even entirely unnecessary.
5. Product Structure Management in O2P

To address the requirements for the product structure management in O2P, the existing concepts of materials, BOMs and the way the master data is interrelated with the system had to be revised. In this section the process of this revision and the resulting model are discussed.

The class diagram below shows the most relevant classes describing the product structure in O2P.

![Class Diagram](image)
Comparing with the class diagram depicted in Figure 8, it should be noted that the two new classes StructureHeader and StructureItem replace the class BOMAssignment presented in the class diagram in Figure 8 in Chapter 3. In an instance of a structure, a material can be associated with another material or with a BOM forming a StructureItem. This way, unlike in the BOMAssignment class where a BOM is tightly coupled with a set of materials, material-to-BOM relationships occur only in an instance of a structure that allows loose coupling. Additionally, with this approach it is feasible to create material-to-material relationships for cases in which generic BOMItems can be replaced with other materials to easily create variants.

Moreover, the concept of EffectiveDate is added in MaterialPlantCost class, in addition to the MaterialVersion and MaterialVersionRotation classes all of which are used as decisive factors in the selection of correct versions of materials that are used in the runtime construction of the product structure. Also, based on the version of the material, costs and sale prices can be calculated accurately for a given customer, date and plant.

5.1 Changes in Material Masters
Material masters were added various new properties which play an important role in the building of the structure. They are listed below.

- Material Type - a basic classification that breaks materials into five groups: Final, Intermediate, Raw, Activity, Equipment.

Final Material is a material type which is the result of an internal production process. Unlike other types of materials such as equipments or raw materials, final materials can be described with a product structure instance.

Intermediate Material is a material type. Intermediate materials are used as generic components of BOMs. They are replaced by more specific materials when building structures. Typically, by choosing different materials to be used instead of these intermediate materials, different final materials are created. This way, intermediate materials allow creating variants at ease.

The other material types (raw, activity and equipment) are used with these classifications which are useful outside the scope of PSM. The calculation of costs and quantities is more straightforward thanks to not being dependent upon other materials.
• **MaterialVersion** class – allows changing to certain attributes without the necessity of creating a new material.

• Effectiveness Granularity – the list of criteria (*Plant, Date, Customer* and *Rotation*) used to select the effective (valid) version of a material.

• **MaterialVersionRotation** class – Rotation is a specific term for the airline catering industry and it allows reuse and simplicity against an inherent problem. That is, the meals that are served on flights change during a predefined period (a week, a month), but these menus are usually referred and considered equal in many cases.

For instance during a week, a *long-haul* flight between London and New York would have;

• Menu 1 on Monday, Wednesday and Friday
• Menu 2 on Tuesday, Thursday
• Menu 3 during the weekend.

Even though the contents of these menus are different, the customer and the caterer refer to this as a *Hot-Lunch* and there is no distinction in between these items in many business processes such as sales and order. The concept of rotation allows another point of distinction on top of **MaterialVersion** into dealing with this business problem. The *Hot-Lunch* is mapped as a **MaterialVersion** whereas the *Menus* are mapped as rotations under each **MaterialVersion**.

### 5.2 Changes in Bill of Materials

A BOM, sometimes referred to as a *Recipe* in the context of CateringPor, represents the list of BOMItems. Below, a “BOM X” and its components are presented.

\[
\text{BOM}_X \{ \text{Item}_0, \text{Item}_1, \text{Item}_2, \text{Item}_3, \ldots, \text{Item}_n \}
\]

![Figure 19 - A BOM and its items (BOMItem)](image)

BOMItems are essentially materials wrapped with additional attributes that are imposed on them when they are used in a BOM. In the context of product structures, by using BOMItems, materials can have certain information such as cost and sale price.
information that is only valid in that instance of a product structure. Above others, the most relevant attributes of a BOMItem are given below.

- Cost Value – Calculated using the base cost of a material defined for a plant or using its structure
- Sale price – A value calculation upon which the cost, applied taxes, labor, the customer depend.
- Scrap – The percentage of loss in the processing of the material
- Supply Type – defines the origin of a material;
  - Internal - produced or fulfilled in-house (e.g. sliced apple)
  - External – ready to consume, usually bought from outside (e.g. apple)
- Quantity

Each Material that is used as a BOMItem falls into a specific classification based on Supply Type and Material Type. These form a decisive factor in the construction of the product structure.

\[ \text{BOM}_X [\text{Item}_0, \text{Item}_1, \text{Item}_2, \text{Item}_3, ..., \text{Item}_n] \]

Figure 20 – Classifications on BOMItems

### 5.3 Product Structure Model

As depicted in Figure 21, Product Structures in O2P are made of materials and BOMs that make up another material of type final material and internal supply. This includes only in-house produced materials that can be broken down to other materials and excludes other materials such as raw materials or equipments and materials that are provided externally. For such a given top-material, there exists a structure for a
material’s version based on its effectiveness granularity (date, customer, rotation and plant).

Figure 21 presents the structure of a final material with all possible associations (black arrows) that can occur in a product structure instance. In the BOM that is associated with the top material, based on the material type and supply type of each BOMItem, an association can be made with another material or with a BOM. For raw materials, equipment and activities, the necessary information (cost, quantity, scrap and so on) is provided from their own master records while other cases necessitate associations with other BOMs, materials and crystallized structures.

**Crystallized Structure** is merely a naming convention to refer to a structure that is used in the composition of another structure. That is to say, in the process of building the structure tree of a final material, other final materials can be used. Their structures must be represented as a sub-tree and they cannot be altered while forming other
structures, therefore making them “crystallized” in a way. In order for the final materials to be used as components in another structure their structures need to be completed.

Unlike BOMs which describe only one level, the product structure drills down through all the materials that can be broken down to its components. They can be used within each other via crystallized structures to describe more complex materials. This provides the manufacturer a holistic view of the goods that must be procured in the entire production process.

Figure 22 - Product Structure Example

Figure 22 illustrates an example of the product structure of CSEU (Cold Snack Europe). In this structure breakdown:

- **CSEU** and other final materials are described with a structure.
- Material **Ham Portion** is an intermediate material, since it is an internal supply material. In this structure, **BOM 101** is associated with it.
Material Juice and Fruit are intermediate materials, since they are external supply materials; they are not associated with a descriptive BOM but with external supply materials Apple Juice and Banana instead.

- 4 Sliced Ham 10g is a final material. Its structure is defined separately and used in this instance as a crystallized structure.

In order for a product structure to be consistent and used in other processes, for instance in proposal management or in procurement planning, it must be complete. The completeness can be understood from the following perspectives.

- Each component must be defined with a breakdown of components if applicable. Basically, final materials should have valid breakdowns of components from which they comprise. In addition, all the intermediate materials must either be associated with a BOM or another material.
- The cost information must be available for every material in the structure.

The cost calculation and the quantity explosion are processed dynamically in runtime. Based on the information (plant, date, customer and rotation) in the top material, the correct versions of each material are selected for the structure composition. After the structure is built, if the structure is complete, the explosion of quantities and cost calculations based on the quantities are made starting from the lower-most items. Using a bottom-top approach, the values are propagated to upper levels to define the individual cost and sale price information for every material in the structure. If any material is missing, then the appropriate cost information and the structure is considered incomplete, and the cost computation is skipped.

5.4 Implementation
For the application of the product structure model, the aim was to find a way to concentrate all the information presented in the model and avoid switching between multiple web pages, which are highly common to ERP transactions. Additionally, using grids and basic forms with overwhelming amount of information are also excessively exercised in the implementation ERP systems. It was considered that for the prospective PSM component, these traditional approaches should be replaced with more natural interaction. Possibly, one of the most natural interactions for altering a hierarchical product structure is to use a tree representation that can be manipulated based on the rules in the model.
As for the technical platform of the PSM, a Rich Internet Application\(^5\) (RIA) was considered from the very beginning of the project. Unlike other web applications, RIA applications conventionally run in a plug-in on the client side. With similarities to desktop applications, RIAs utilize processor capabilities better than common server-side web applications, thus, providing better performance and user experience, especially when dealing with graphics. Since the development environment of O2P is the Microsoft .Net Framework\(^6\) backed with business objects in ATL COM\(^7\), the most suitable choice was the Silverlight\(^8\) RIA Platform.

The first version of the product structure management transaction was written for Windows OS platform, using a combination of C# and C++, consisting over 20,000 lines of code.

**5.5 Features and Usage**

The Product Structure Management transaction is loaded for a selected MaterialVersionRotation instance. That is, a product structure is present for a version of a final material based on a date (effective date), plant, customer and rotation information. This information is used in for selecting the correct version of the other materials and BOMs used in the construction of the structure tree.

As the PSM application is loaded, the structure of the tree is built. The quantity explosion is made. In addition, the tax values, sale price and other customized cost values are calculated for all the applicable items in the structure in this order. The entire process is done in a recursive manner in runtime using the business objects in the server side. Later, the resulting tree data structure is serialized in the XML format and then it is sent to the client for visualization via web services.

In Figure 23, an overview of the structure tree of a material is presented. The materials and BOMItems (Materials in BOMs) are drawn as boxes and BOMs as bigger containers. Color coding is used for indentifying the different Units such as blue for ‘Cold Kitchen’ and yellow for ‘Bakery’.

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\(^6\) [http://www.microsoft.com/net](http://www.microsoft.com/net)

\(^7\) [http://en.wikipedia.org/wiki/Active_Template_Library](http://en.wikipedia.org/wiki/Active_Template_Library)

\(^8\) [http://www.silverlight.net/](http://www.silverlight.net/)
In Figure 23, the collapsible details panels on the right shows additional information on the selected item for material and BOMItem attributes in addition to cost and price values. In the top right, the various controllers can be seen, from right to left, it consist of the following.

- Zoom slider to adjust the scaling;
- Home button for returning back to an initial visual state upon the first load;
- Search Panel for finding materials or BOMs to be included in the structure;
- Information Panel for retrieving extra information on the visualized tree such as the total cost of items that follow a certain pattern;
- Undo and Redo functionalities;
- Refresh button for forcing a reload of the structure at will;
- Full Screen trigger;
- Settings Panel for altering simple user preferences; and
- Publication functionality for downloading an extract of the structure as a document based on a predefined template.
When building a structure, the materials or BOMs are chosen from the result set of a search (using the panel on the left in Figure 23). The selected item is dragged onto a BOMItem or the root material to form a StructureItem relationship. Only then is the list of all the StructureItem associations in the structure serialized and sent back to the Web service to be saved in the database. Following the save, the process of building and loading the structure is repeated.

Although they are used in the structure, the materials and BOMs are defined separately in their corresponding transactions: BOM Management and Material Management. That is to say, a material cannot be created from within PSM. Similarly, a BOM can only be formed in the BOM Management transaction and a material cannot be simply added to a BOM in the PSM in O2P. As has been noted earlier in this chapter, only Material-to-BOM and Material-to-Material associations can be made by attaching a material or a BOM to an existing material in the structure and this association does not change the BOM outside that structure instance.

Figure 24 – A BOM and Materials in a Product Structure
As shown in Figure 24, the external supply materials are displayed in the top levels of a BOM container, whereas, the internal supply (in-house produced) materials are represented in the lowermost level in a BOM. Intermediate materials are used for both supply types. The number areas are further explained as follows.

1. **Material-to-Material** association occurs where a BOMItem which is an intermediate material and of external supply, is replaced with equipment.
2. An intermediate material without any overriding material or BOM. The icon in the bottom right corner indicates the structure is incomplete due to this item.
3. **Material-to-BOM** association occurs when a BOM is selected from the search panel and attached to an intermediate BOMItem with internal supply, in order to describe the contents of that intermediate material for this structure instance.
4. **Material-to-Material** association is where a BOMItem, which is an intermediate material with an internal supply, is replaced with a final material. Since each final material must have its own structure, this structure is also presented here. However, as explained earlier in this chapter, this substructure is crystallized and cannot be manipulated from within the containing structure. The double lined connector is an identifier for crystallized structures in PSM.
5. A final material which is a BOMItem but not a StructureItem, since it is not replacing any intermediate material. It also has a crystallized structure that is displayed in this structure.

Another important feature of PSM in O2P is the ability to create *Options Structures* where more than one material can be associated with a BOMItem in the structure as alternatives. In O2P, options structures are used as templates from which more specific product structures can be easily derived by simply selecting one alternative for each intermediate BOMItem. Figure 25 shows an example of an options structure with selected alternatives.
Finally, as a supplementary but equally important feature, the product structure can be extracted to a downloadable document using publication feature. This feature provides a more formal representation of the product structure which is used in various business processes for instance in the proposal stage in sales.
6. Discussion of PSM in O2P

In this chapter, along with its implementation, the solution model is evaluated against the predefined list of major capabilities. It should be noted that this thesis work does not claim this solution is superior to others in anyway but merely an alternative that serves as an answer to the needs of the platform in question.

6.1 Evaluation against Predefined Features and Capabilities

In section 3.4, the motivation for a product structure as well as the needs from it were numbered. This part evaluates the PSM in O2P based on this list and a small number of additional specific features.

Versioning

The versioning problem is necessarily related to the difficulty of identifying the list of factors that affect a product’s structure. The solution model identifies these factors as given below.

- Plant
- (Effective) Date
- Customer
- Rotation

These are the primary factors when deciding whether a (final) material needs a MaterialVersionRotation and therefore a different product structure. This is mostly due to the fact that they are all decisive in costing and availability of materials and also, as a consequence, BOMs. Using of these set of attributes adequately narrows down the scope of product structure and assures that the information presented in the breakdown is precise. Besides composition, the accuracy of the cost information in particular requires fair specificity.

Material Classification

The categorization of Material masters is important not only to the product structure related processes but also to many others for the convenience and reuse it provides. In the construction of product structure paradigm in O2P, materials are classified in two ways.
- Material Types: Raw, Activity, Equipment, Final and Intermediate
- Supply Types: Internal and External

The list of definitions for Material Types is not arbitrary but they may not be comprehensive either. Product structures with their use in product planning are required for in-house produced products which are described as internal supply type and final materials. Materials with other combinations are also used within the structures but they do not have their individual product breakdowns.

**Reuse**

In the construction of the model, reuse has always been a primary concern. As a result there are a handful of concepts that serve this purpose.

Firstly, the use of versioning provides reusing of Material records. MaterialVersion entries are created for a Material master for special treatment especially in cost calculations. For each rotation of a MaterialVersion, a MaterialVersionRotation instance is created to define that particular product’s structure breakdown. By doing so, the need for creating different material records is eliminated which otherwise would result in numerous Material records that have a lot in common. Table 1 represents the total count of Material classes and subclasses that are of material type final. 12342 different versions of materials exist but 5939 material records suffice on account of versioning.

<table>
<thead>
<tr>
<th>Class</th>
<th>Record Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>5939</td>
</tr>
<tr>
<td>MaterialVersion</td>
<td>11210</td>
</tr>
<tr>
<td>MaterialVersionRotation</td>
<td>12342</td>
</tr>
</tbody>
</table>

Table 1 - Total count of records in the CateringPor Database

Additionally, the use of intermediate materials allows for the reuse of BOMs. For each product structure tree, at least one BOM must exist that describes the root material. But instead of creating a new BOM for each structure, to achieve different end products, it suffices to simply create a structure association with another BOM or a material with the intermediate materials of that BOM. This way, a more generic building stone that
can be shaped for variety is achieved. As can be seen in Table 2, total number of BOMs is less than half of product structures count due to the use of intermediate materials.

<table>
<thead>
<tr>
<th>Class</th>
<th>Record Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOM</td>
<td>2717</td>
</tr>
<tr>
<td>Product Structure</td>
<td>5500</td>
</tr>
</tbody>
</table>

Table 2 - Total count of records in the CateringPor Database

Last but not least, the options structures serve as a template from which more specific end products can be derived. Especially in the airline catering industry, rotations of meal types can be very similar to each other. This template approach is very beneficial in creating and maintaining a family of products which share many common aspects.

**Different Views for costing**

As explained earlier, PSM module is designed to build structures in the runtime using loosely coupled relationships among BOMs and materials. Therefore, the system is flexible enough to support simulations and making runtime calculations without much need for predefined, hardcoded cost and quantity values. The PSM module provides basic cost and sale price information for each and every material that is used in the structure. Additional views of costs and sale prices based on the customer configurations are calculated and reflected to the structure presentation. Common examples of these customized views include the following costs.

- Applied tax values per item
- Labor-free cost of BOMs
- Cost values in different currencies

These views support CateringPor in different contexts when they are needed for internal operations, proposals, sales and particularly on the requests of client airline companies.
BOM vs. Product Structure

The stance of the revised BOM concept is clear in the product structure paradigm. A BOM still constitutes a list of materials with their quantity information. However, they no longer form a part or a product outside the definition of a product structure. That is, BOMs and materials do not have the direct binding that BOMAssignment class supported but they can form a part or a product within a product structure instance.

As for the question of whether product structures and BOMs should have different views such as engineering, design and manufacturing, for the time being, there is no such feature to support design or engineering views. The product structure architecture and the information conveyed are aligned with manufacturing purposes. However, as a significant bonus, the cost and price information which is not conventionally presented in PSM is present in O2P. From manufacturing point of view, it is invaluable to be able to acquire real-time and simulated cost and price values in convenience.

6.2 Known Issues and Technical Considerations

There are some notable shortcomings and limitation to the features of the product structure management in O2P.

The product structures in O2P are trees that can easily grow and become huge. This directly affects the time spent for the construction of the product structure in runtime based on a few parameters. Although the module performs fairly efficient for most structures used in the production systems so far, for these other special cases, the delay of the Web service response is significant, therefore, an enhancement in the processing of the structure might be necessary.

Moreover, the size of the product structure tree affects the graphics performance and the quality of the user experience. The Silverlight platform makes it easy to manage a great deal of graphical items but there is a limit which is the capacity of the computer processor. For excessively big trees, the PSM User Interface loses its smoothness.

Another important issue is the retention of the product structure data due to the loose coupling of BOMs and materials. The associations among BOMs and materials are made within the scope of a product structure and they do not change the BOM or material records. But the master data records of a BOM or a material that is used in a structure can be changed from the outside of PSM using the Material Management or
the BOM Management transactions. Altering BOMs and materials can cause them to become unsuitable for the structures they were used in. However, this is a drawback that comes as a tradeoff for the chosen product data management strategy of building immense product structures on the fly and managing them in a lightweight manner.
7. Conclusions

Manufacturers need efficient systems to keep track of changes to the product structure and make it available for the business processes that require it. Therefore, product structure management is one of the key processes in the ERP. As a result, the definition of the product structure model is critical to the manufacturers. This thesis has explored the use of product structures in ERP systems, identified the issues related with product structures and described an approach to modeling and implementation of a product structure management module in a target ERP.

The first goal of this thesis was to identify the key issues of the product structure management in ERP systems. It was found that the product structures are fundamental to many business processes in manufacturing firms, which are the main target of ERP systems. Moreover, along with material and BOMs, the product structures are considered master data which form the core of information for manufacturing firms. Therefore, in an ERP, the PSM transaction is highly interconnected with other transactions and modules.

It is agreed that in addition to production, there is a need for different product structures for different business activities such as engineering design, sales and order. In fact, it is mainly this aspect that drastically determines the way the product structure modeling is made. Particularly, the extension of ERP capabilities over the activities of design and engineering plays an important role in the scope and functionalities of PSM. As a result, it is discovered that, in an ERP system, it is the purpose of the breakdown which defines the contents of a product structure and the features of the PSM module.

The second research goal was the construction of a product structure model and implementing it as a PSM component in a target ERP, namely O2P. As an answer to this, the needs and motivations for a product structure concept are outlined and the existing modules and concepts related to product structures were identified. Consequently, O2P was investigated for its characteristics with regards to the findings from the first research question. That is, the questions related to the extension towards PLM capabilities and whether it should support different views were answered. A high level collection of modeling approaches was examined for applicability. In light of these prior works and also taking the predefined needs for PSM capabilities into account, a suitable model is suggested. As an answer to the second part of the research question,
the implementation is detailed and practical uses of the PSM module in O2P are explained. The new module was evaluated based on the criteria listed earlier as needs and features.

Although this thesis work identifies the commonalities of ERPs and tries to draw conclusions taking multiple examples into consideration, O2P being the only use case makes it difficult to fully justify the proof of concept for a PSM in all ERPs. As another limitation, the evaluation of the suggested model is claimed to be satisfactory after an evaluation based on previous needs, which are also defined by this work instead of a more thorough approach such as a user study. However, once more, it must be noted that the aim of this research is not to suggest a generic or a superior solution but merely an alternative that complies with the needs of a single target system.

This thesis work can be useful with different ways however following three aspects stand out as significant contributions;

1. In this thesis, a model for product structure management is formulated and the technical details of its implementation are listed. It can help implement or extend a product structure management component of an ERP system.

2. The research in product structure modeling has been quite a rich area. However, the examples of mapping of this knowledge in the ERP systems are relatively scarce. This work can prove useful in the future research in this area.

3. The details of implementation with its business environment can provide insight to others that would like to develop a parallel solution with similar business needs.

The PSM in O2P is used intensively in the processes of proposal management in pre-production stages and certain flight preparation related activities. The current version of the product structure management transaction reflects the immediate needs of the platform in addition to those that are not immediate but still visible to the Processware and CateringPor. These needs and the implemented software together are likely to serve as the foundation of PSM functionality as O2P continues to expand in years to come. The PSM component was one of the biggest initial steps in the introduction of material requirements planning module to O2P. As the remaining
transactions emerge the product structure model is going to evolve and the PSM component will change.
References


[Rathinakumar, 2000] A. Rathinakumar, Implementation issues in ERP. In: ICSTM.


