INTERNATIONAL DESIGN CONFERENCE - DESIGN 2014
Dubrovnik - Croatia, May 19 - 22, 2014.

BOM-CENTRIC PRODUCT DATA MANAGEMENT FOR SMALL AND MEDIUM MANUFACTURING ENTERPRISES

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Keywords: BOM, engineering BOM, manufacturing BOM, green BOM, process BOM, enterprise BOM, PDM, SMEs

1. Introduction

Product data management (PDM) is an integrated system or service which controls and manages all data and information flow generated in life cycle of products covering concept definition, design, production, shipment and after service [Lee et al. 2013]. SmarTeam® as a representative commercial PDM system stores the information generated in CAD design, fabrication and maintenance stage, integrates manufacturing process with automated workflow and change management function, and provides users with security, revision, technical document link, structure management and distributed execution function. On the contrary, TeamCenter®, another commercial PDM system, supplies users with integral structure of products, makes assembly model of products collaboratively, performs top-down design and configuration and change management, and shares designed CAD model on work-flow based process. In summary, those two systems share design models in product life cycle and manage product data on work-flow based process. Even though commercial PDM systems have a lot of nice functions, they are still heavy and expensive system to apply to small and medium manufacturing enterprises (SMMEs).

One of the important functions in a PDM system is to manage the structure and configuration of products. Product structure represents the hierarchical assembly relationships among components and requirements of each component, and product configuration describes assembly specification and option of products. Those two information should be managed systematically for PDM to apply to manufacturing enterprises [Kim 2000]. This study proposes a light and user-friendly PDM system dedicated for SMMEs which connects with several bill-of-materials (BOMs) and manages drawings, technical documents and design history. A BOM has a hierarchical format with the topmost level showing an end product and the bottom level showing individual components thereof to assemble, playing a role of basic reference to get started in the wide spectrum of manufacturing activities such as product design, process design, production, sales and after-sale servicing. In other words, the BOM is represented with different views because it requires different information according to application areas in manufacturing [Mather 1988]. As depicted in Table 1, the BOM is classified, depending on usage in respect of manufacturing activity, into sales BOM (sBOM), engineering BOM (eBOM), green BOM (gBOM), manufacturing BOM (mBOM), process BOM (pBOM) and service BOM (asBOM), while being classified, depending on type of structural representation, into Traditional BOM (T-BOM), Modular BOM (M-BOM), Percentage BOM (P-BOM), Variant BOM (V-BOM) and Generic BOM (G-BOM) [Van Veen 1992], [Cunningham et al. 1996], [Hegge and Wortmann 1991], [Park 2004]. This study focuses on the former usage-oriented BOMs rather than the latter.

Table 1. Classification of BOMs subject to usage and structural representation

Category	Type	Explanation
Usage in manufacturing activity	engineering BOM(eBOM)	show product function hierarchically
	sales BOM(sBOM)	calculate pre-estimated cost of products
	green BOM(gBOM)	describe material information of products
	manufacturing BOM(mBOM)	describe manufacturing sequence and relation
	process BOM(pBOM)	show manufacturing process information of products
	service BOM(asBOM)	show disassembly sequence of products for maintenance and remanufacturing
Structural representation	Traditional BOM(T-BOM)	represent BOM structure independently by products
	Modular BOM(M-BOM)	manage the modules grouping with common and option components
	Percentage BOM(P-BOM)	show the ratio of components in products
	Variant BOM(V-BOM)	represent a lof of options with a BOM structure
	Generic BOM(G-BOM)	make the relations among options rules and generate BOMs with options

The sBOM, created in the phase of product planning, is formulated by referring to BOMs of existing similar products available, being usually utilized to approximately predicting precosting. Meanwhile, the eBOM, created in the phase of product designing, is a recipe for manufacture by containing profiles, listings and quantities of all parts/components and detailing their structural functions in relation to a finished product. In particular, an engineering BOM is generally called simply as a BOM since it provides core information to the fullest for the subsequent manufacturing process. The gBOM is introduced with an aim to robustly respond to the international environmental regulations by further containing information on materials of product ingredients to the concept of eBOM. The mBOM, created in the phase of process designing, includes, in addition to on the eBOM, parts list required for manufacture, assembly relationship and sequence of parts in a batch, stock information and ways of utilizing alternative products. The pBOM contains more information based on mBOM such as information on facility engaged in manufacture of each parts, work method and process conditions. The asBOM being created specifically for after servicing mainly relates to the parts' characteristics management in conjunction with product maintenance by identifying serviceable or replaceable parts and their warranty policies. A number of researches by far have proposed bills of materials depending on usage, but there are multiple nomenclatures in naming a BOM having the same usage. This study is to present a BOM-centric product data management system to support the product development by focusing on four typical types of BOMs subject to usage - that is, eBOM, gBOM, mBOM and pBOM.

2. Usage and management of BOMs

2.1 BOMs in an enterprise

Diverse forms of BOMs are under utilization for discrete manufacturing activity in most companies, but each BOM, although free definable, has an information system different with each other in a fashion seemingly independent. It is an enterprise-BOM that is developed in an attempt to manage and integrate individually scattered BOMs in a systematic manner. That is, the enterprise-BOM indicates the enterprise-wide integrated data management of individual BOMs by the manufacturer in regard to product specifications and parts data throughout the product life cycle.

The core characteristics of the enterprise-BOM is connectivity and uniqueness of information, where the former pertains to linking and maintaining both product specifications information and parts information closely in all stages of defining products and parts, while the latter pertains to sustaining the latest fresh information on product specifications and parts in an integrated management system to allow all such information to be utilized without temporal and spatial limitations [SIEMENS PLM Software 2006], [Jeong 2007]. Seo et al. proposed a construction methodology that aims to manage dispersed product information under the complicated collaboration process by applying the concept of enterprise-BOM [Seo 2011], in which the Zachman Framework was employed to integrate all product information relating to enterprise BOM in a corporate dimension [Zachman and Sowa 1992]. Kim proposed the framework of enterprise BOM structure in automobile industry [Kim 2007], and Li developed the enterprise BOM appropriate for aerospace industry [Li et al. 2008].

2.2 Transform and usage of BOMs

A variety of researches have been made on transformation of BOMs even up to now, most of which have been focused mainly on transforming eBOM into mBOM [Chang et al. 1997], [Ou-Yang and Pei 1999], [Ou-Yang and Cheng 2003], [Liu et al. 2005], [Xu et al. 2007]. What is in common in conventional studies is that eBOM should be preliminarily designed prior to mBOM and the information on assembling sequence among parts be added in transforming eBOM into mBOM. These days researches extend transformation into pBOM inclusive of manufacturing information beyond mBOM [Liu and Sun 2009].

The main purpose of BOM transformation is to efficiently manage BOMs in the level of organizational information systems such as MRP (Material Resource Planning), PLM (Product Lifecycle Management) and PDM (Product Data Management). Therefore, integrating transformed BOMs into the enterprise information system has lately received much attention in researches [Zhu et al. 2007], [Meng et al. 2007], [Liu and Sun 2009].

2.3 Integrated management of BOMs

The manufacturing process is divided into design stage and production stage in a broad sense, where eBOM is utilized as reference information for the former and mBOM for the latter. This implies that key BOMs typically adopted by a manufacturing enterprise will be eBOM and mBOM [Yu-xin 2009]. All other forms of BOMs except them are subtypes derived from these two generic BOMs. BOMs specified for sales, product planning and response to environment regulations are branched from eBOM, while BOMs dedicated to production and assembly, packing, transportation, installation and after-servicing are rooted from mBOM. In this context, since mBOM is a creature generated by adding, deleting or transforming the eBOM as appropriate, the eBOM shall act as criteria when transforming it into mBOM.

The BOM-centric product data management proposed by this study commences tracing back to the concept of enterprise-BOM. In this sense, the study primarily defines four typical forms of BOMs - eBOM, gBOM, mBOM and pBOM - that are widely used in the process for product development, and then extract the correlation amongst them to propose a BOM-centric management system as a means of accomplishing systematic and integrated data management of those four BOMs. In addition, the study discusses gBOM derived from eBOM to respond to international environmental regulations that become hot issues, and suggests pBOM to manage detailed process information of each parts based on mBOM. If the BOM-centric data management system proposed by this study is put into practice, it is possible to perform modification, alteration and transformation of BOMs in an integrated and consistent way.

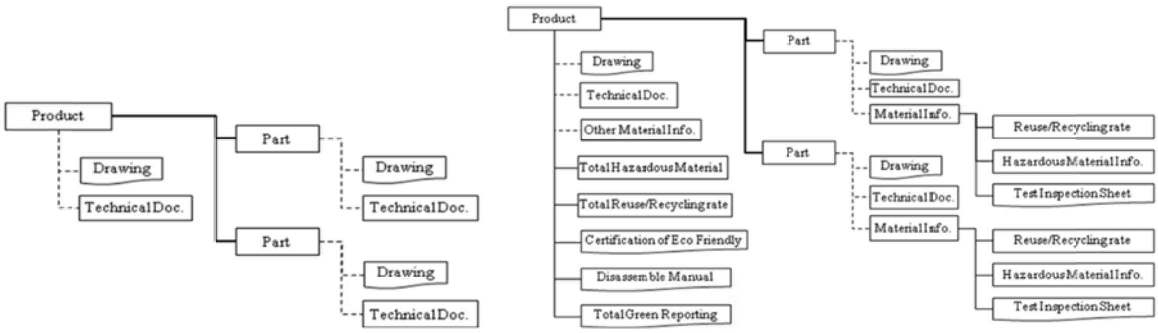
Of course, large-size global manufacturers have constructed refined management systems specific to their own product development environment and put them, including solutions as well, into application to their worldwide networks. In the context what is meant by this study is to propose a BOM-centric management system that is able to be realistically and easily utilizable by small and medium manufacturing enterprises (SMMEs) which are relatively less competitive in terms of procurement of investment and manpower.

3. BOM-centric product data management

3.1 BOMs in design stage

As depicted in Figure 1-a), eBOM represents hierarchical structuring relations between an end product and its individual components/parts in view of product functionality, usually containing technical information as well as parts profile, listing and quantity. Therefore, it is formulated in the product design stage, being utilized as reference in the succeeding manufacturing process. It is needless to say

that, once an alteration of design has been made, the eBOM to be referenced as core data should be accordingly altered along with all information thereon to be modified as appropriate. In this regard, if such change or modification is missed in part or incompletely carried out, the outcome will likely be a failure such as unacceptable defect in a product.
As shown in Figure 1-b), the gBOM is one that further supplements material information as to product and its individual parts to the conceptual eBOM so as to be green compliant to international environmental regulations for manufacturing companies. It should be informative to the extent that a designer is able to identify material distribution, whether toxic substance is included and ratio of reusable material. Based on this, the designer will finally conduct optimization of material design by totally relying on it. In addition to such usage, gBOM is also used to prove no inclusion of any toxic/dangerous material infringing relevant regulations applicable in the pertinent sales territory.

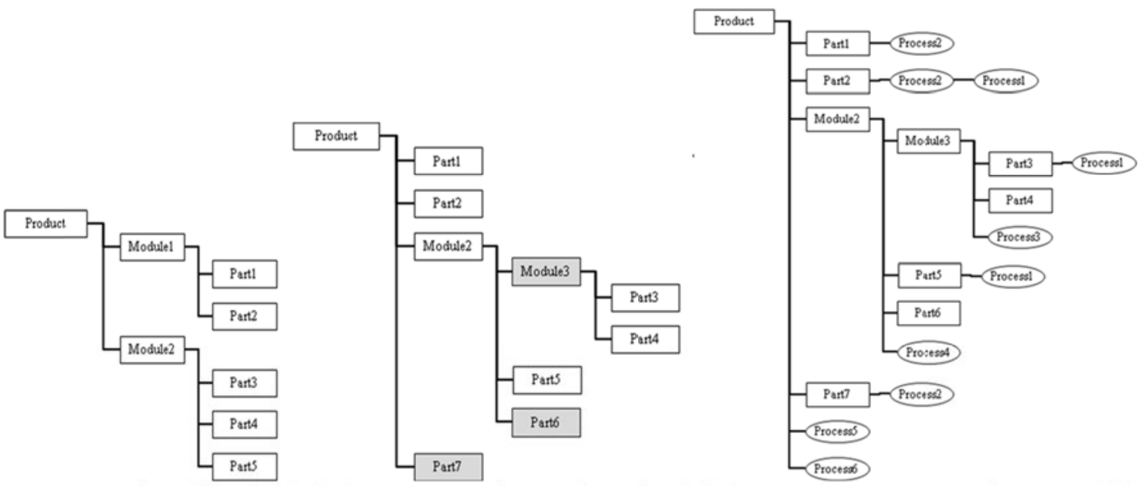


a) Structure of eBOM b) Structure of gBOM

Figure 1. BOMs in design stage

3.2 BOMs in production stage

mBOM is the hierarchical representation describing assembly sequence and reguirements of components. The mBOM is made by adding components and interim modules required for manufacturing, deleting meaningless modules in fabrication, and rearranging components by production sequence based on eBOM. Figure 2-a) is an example of eBOM of a product functionally consisted of with module #1 including part #1 and 2, and module #2 comprising part #3, 4, and 5. As depicted in Figure 2-b) showing the mBOM of the product, the module #1 of eBOM is deleted because it is no meaning in fabrication, the module #3 is added to assemble the part #3 and 4, and the part #5 and 6 is also added to manufacture the product.



a) engineering BOM b) manufacturing BOM c) process BOM

Figure 2. Concepts of eBOM, mBOM, amd pBOM

A pBOM is a type of BOM that further includes detailed process information on end products, modules and parts, which might be advanced from the concept of mBOM. Whereas in the past manufacturing process related information required separate documentation such as process drawings, work order sheets and the like, the latest management system toward BOM-centric product data management requires the concept of pBOM integrating manufacturing process information together with mBOM. The conceptual differences between mBOM and pBOM are well depicted in Figures 2-b) and 2-c).

3.3 Relation between BOMs

As described before, the eBOM figures out the hierarchical structure among parts including general information on parts. A gBOM goes further by adding material information by parts to the concept of eBOM to cope with international standards on the environment such as WEEE, RoHS and Reach for which it contains information on criteria, material, reuse/utilization, weight, percentage, etc. Meanwhile, a mBOM refers to the assembly relationship of parts, which provides basic information necessary for process design. A pBOM has a feature of adding information on manufacturing process of each parts to the concept of pBOM.

In order to perform transformation among BOMs that are needed in the course of product development, it is vital to input information of eBOM as the most fundamental basis, which implies that the eBOM is reborn to be gBOM while passing through material designing or mBOM while passing through process designing. In other words, the mBOM is created by transforming the eBOM fittest to the manufacturing procedure/sequence and adding or deleting modules and parts required for manufacturing process. With one step forward, the pBOM is created by adding detailed information on manufacturing process with respect to each parts to the concept of mBOM. Such transformation in between a series of BOMs is made selectively as intended by executors. For example, those interested in manufacture will transform the eBOM into the mBOM, while those interested in the environmental regulations will transform the eBOM into the gBOM.

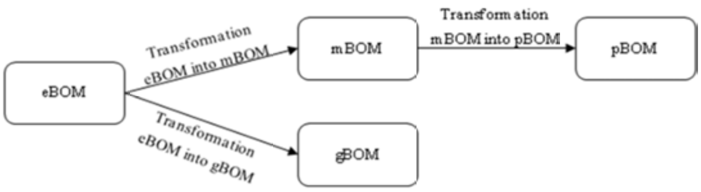


Figure 3. Concept of BOM transformation in BOM-centric PDM

With regards to transformation of gBOM, the tree structure of eBOM itself remains unchanged, but information on materials is to be added as per each parts positioned at last nodes. The information to be added for such transformation includes information on materials, content of toxic/harmful substances, rate of reuse and utilization, weights, relative percentage thereof, test reports, etc. Figure 4 shows the relationship between eBOM and gBOM. To summarize, in order for eBOM to be transformed into gBOM, it is required that information associated with the environment regulations be linked with lower hierarchical modules/parts based on the structure of eBOM.

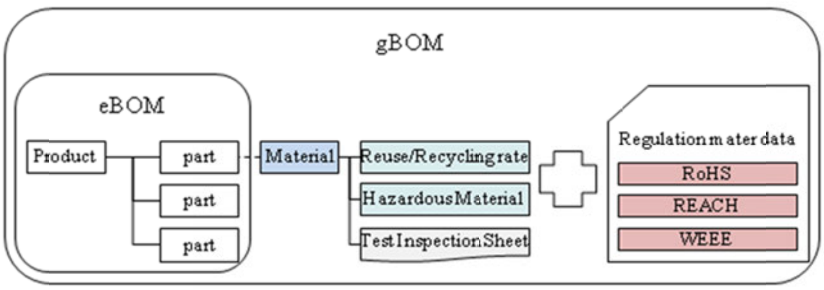


Figure 4. Relationship between eBOM and gBOM

Likewise, information on assembling sequence of parts is needed to make eBOM to be transformed into mBOM, where the tree structure of eBOM is to be modified or altered to the new tree structure in accordance with the sequence for production and parts assembly. The pBOM needs information on production process of parts and assembly process of modules in addition to the concept of mBOM. In the context the information on production process will be connected to nodes of each parts to give ideas of how parts are produced, while the information on assembly process will be connected to nodes of each product and modules to provide schematics of how parts are assembled. Figure 5 shows how a pBOM is formed by adding information on production process to the concept of mBOM.

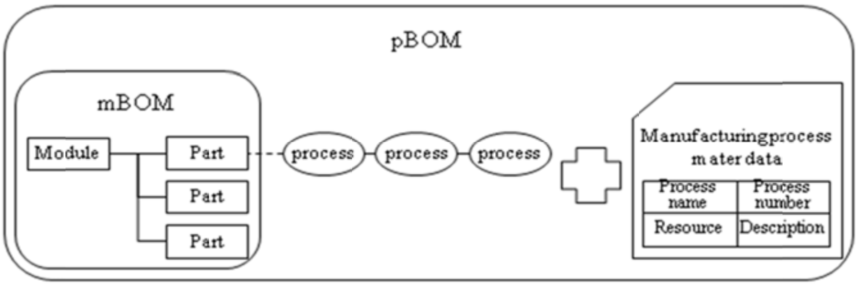


Figure 5. Relationship between mBOM and pBOM

Figure 6 refers to transformations of eBOM, gBOM, mBOM and pBOM by taking a mechanical pencil as an example regarding BOM transformation as described by far. As shown here the mechanical pencil comprises a total of 15 parts including case, cover and tube, where design information of those parts is able to be represented in a form of eBOM. If the eBOM, once created, is connected to lower hierarchical parts with addition of material information, it is transformed into gBOM. Only when such transformation into gBOM is completed, a user is ready to judge suitability of relevant environmental regulations applicable in making the mechanical pencil of consideration by calculating content of its ingredients (materials) and verifying whether harmful material is included.

The mBOM is created by way of adding information on assembly sequence as well as two process parts to the formulated eBOM. As shown in Figure 6, mBOM and eBOM have parts assembly sequences different with each other, and 6 parts out of them are in advance assembled to form a socket. In particular, #16 part, that is lubricant, is added in the course of assembling a socket module, in which it does not indicate a specific functional part in design, but indicates a process parts needed additionally in the assembly sequence. A finished product is to be made by assembling the socket module with parts #10, #13, #14 and #15 to form a tube module, adding 6 parts to this module, and lastly affixing a part #17 that is a label to the product.

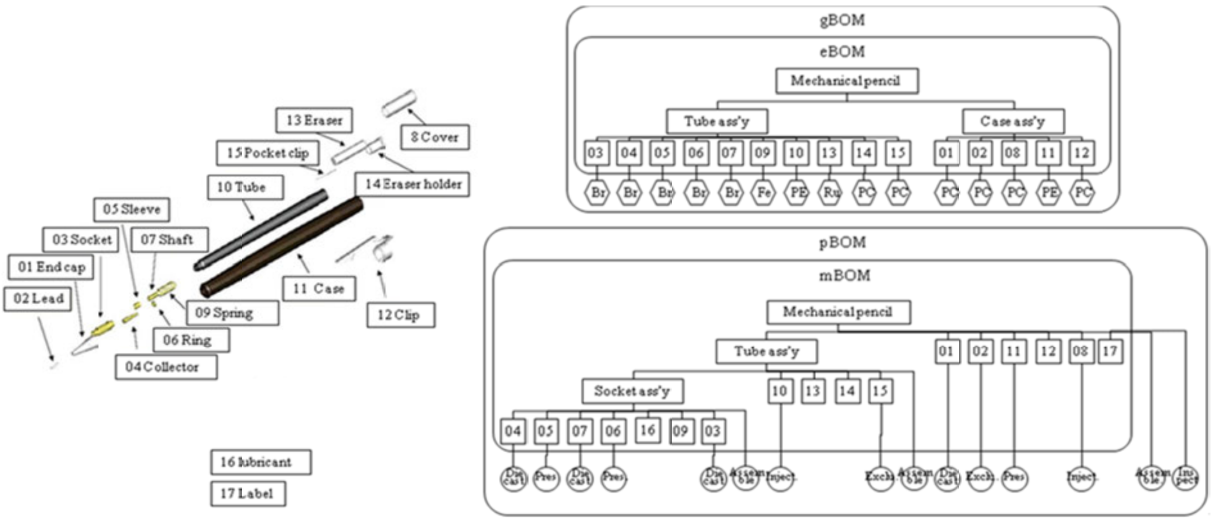


Figure 6. An example of BOMs

Finally, the mBOM is to be transformed into pBOM by adding to it the information on production process of parts. Note that parts included in the process indicate those directly produced by taking advantage of own production facility of a company, and parts such not included in the process, such as #16, #9, #13, #14, #12 and #17, are those procured via outsourcing. An end product of mechanical pencil is made through the assembly process as to socket module, the assembly process as to tube module, the process of module-to-module assembly and the inspection process as to finished products.

4. Implementation of BOM-centric product data management

Based on the content designed, a BOM-centric PDM system has been drawn out with the architecture as shown in Figure 7, where common functions such as security, version, numbering system and search were separated into the region of Platform & Service. Moreover, in the BOM region, modules were constructed, based on parts constituting BOMs, into sections of material, process, drawing, document, design modification and collaboration. Although a BOM is normally managed with the use of one BOM table, it was herein devided into eBOM and mBOM through the architecture type, which addresses that types of BOMs are expandable through the architecture type as many in number as one likes.

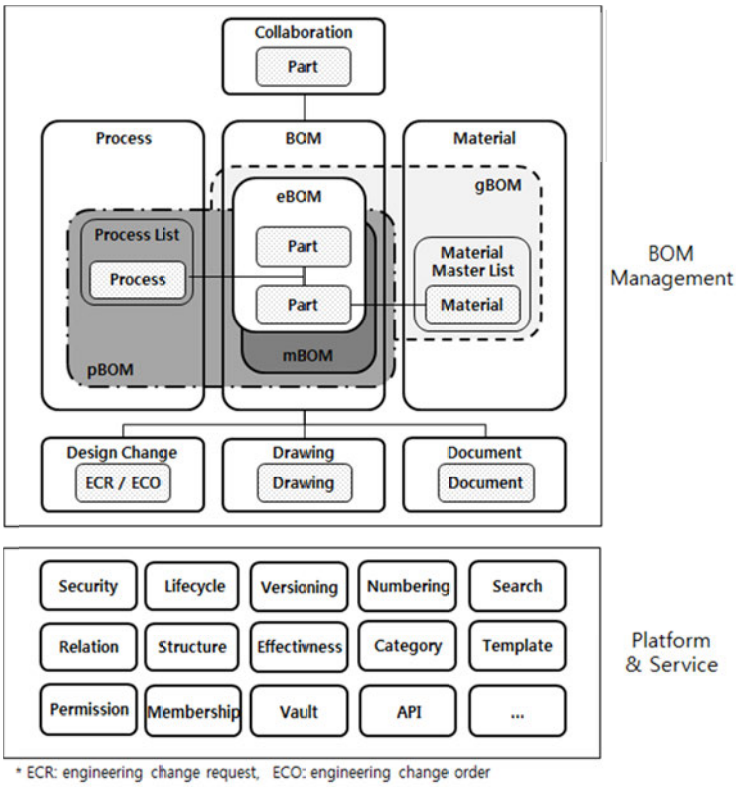


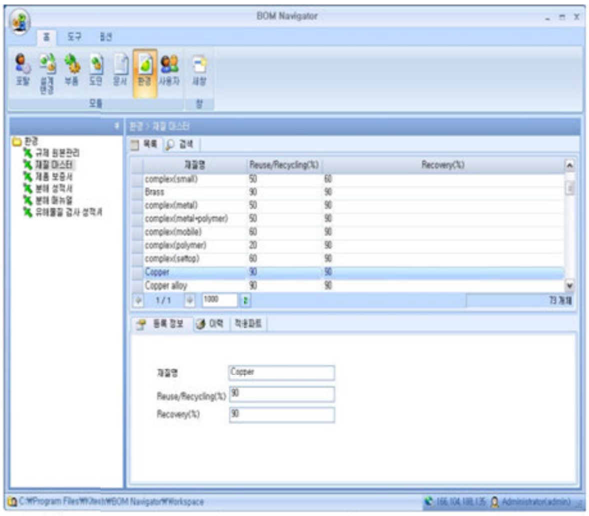
Figure 7. Architecture of BOM-centric PDM system

4.1 Management module of green BOM

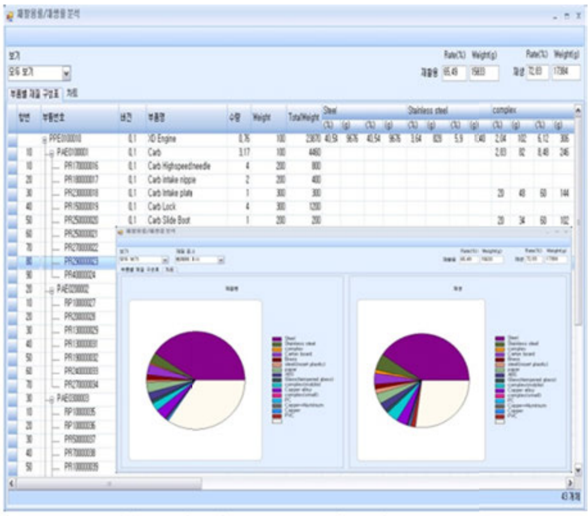
A module for managing gBOM is one that creates and manages gBOM by adding information relating to environmental regulations based on eBOM, which is largely composed of functions of parts management, product management and standards management. At this point, the parts management pertains to registration/management of certified material report, registration/management of content of harmful material and management of reuse and utilization rates by parts, where an alarm function is offered when validity expires so as to keep valid material test reports and an updating function is also offered enabling the user to modify the test report in a batch with respect to the same material. The product management pertains to functions of automatically calculating total content and percentage of ingredients that constitute a product by collecting data on materials of each part, and, based on them, providing information on inclusion of harmful material or not in a product, its content and reuse rate. In addition, it renders a function of comprehensively reporting environmental regulation related information based on the result calculated, while managing certificates compliant to environment regulations along with manuals on decomposition of recyclable materials that are usable for disposal of products.

The standards management pertains to creation/management of material information standardized for companywide common use by determining and registering official nomenclatures and division codes as to materials. It specifically contains standardized attribute information of materials such as reuse, recycling, inclusion of harmful material and content, and also offers functions of providing original scripts of environmental regulations set forth by each country and managing important schedules. Figure 8 shows examples of screen images as to major functions available in a management module for gBOM.

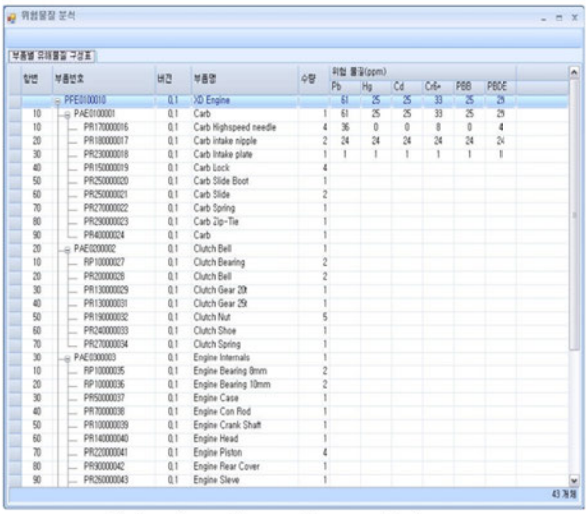
Figure 8-a) is an example window to register detailed gradient, recycling/reuse rate, and hazardous substance of standard materials used in an enterprise. Figure 8-b) shows the reuse ratio of materials used in each component and the total recycling and reuse volume and ratio of each product/component. And the detailed contents, volume and ratio of hazardous substance calculated are displayed in Figure 8-c).



a) Create & link the master data of material used



b) Calculate recycling/reuse rate

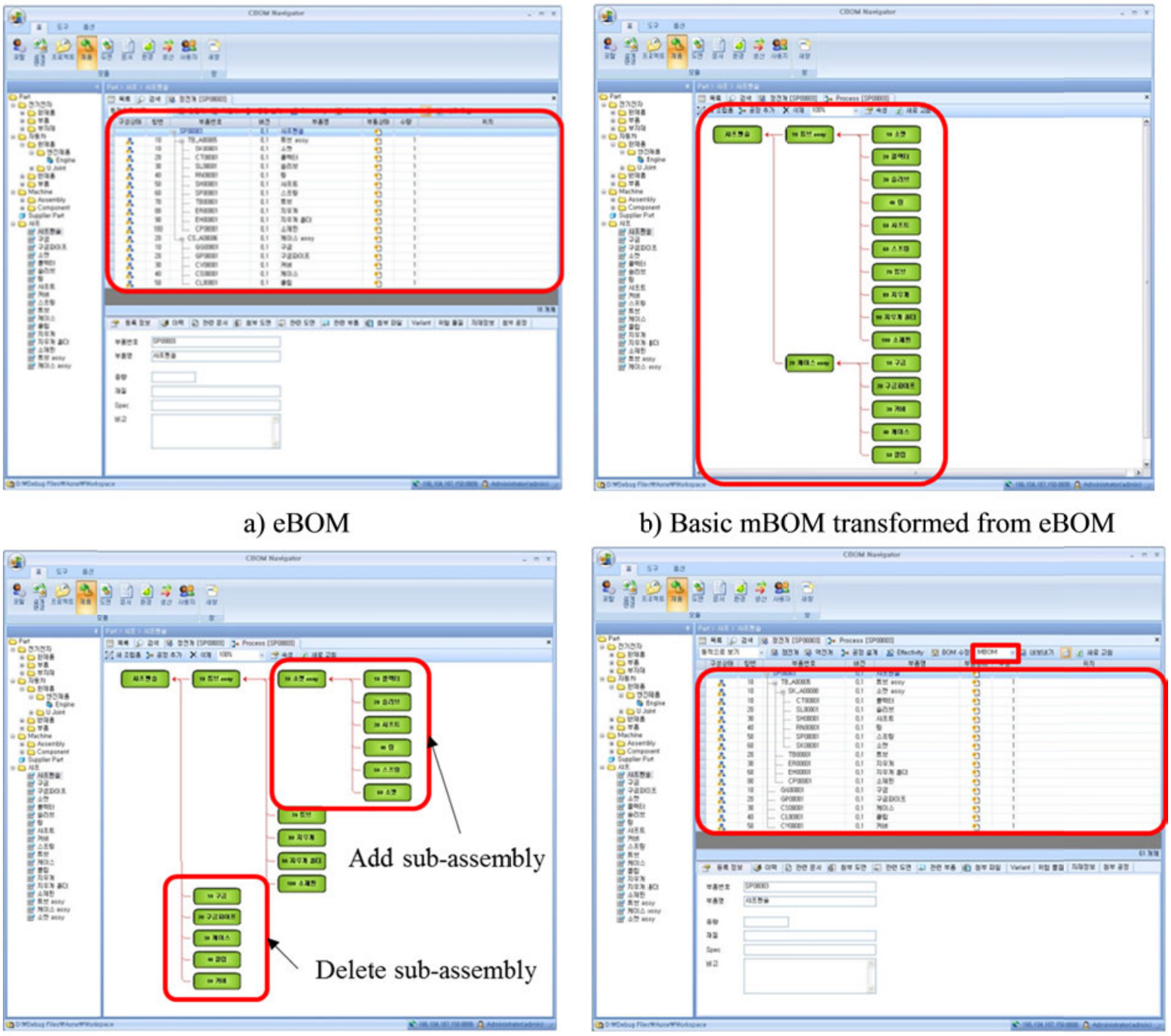


c) Analyze hazardous substances

Figure 8. Main functions of gBOM management

4.2 Management module of manufacturing BOM

The mBOM-specific management module refers to creating, editing and managing mBOM which provides informative clues on the preceding/succeeding relationship among parts in the manufacturing domain and their assembly relationship in addition to the concept of eBOM. To create a mBOM it is indispensible to go through process designing. For this, it is needed, to begin with, to select a target eBOM and import an eBOM to construct a mBOM in the screen of modeling-based process design, and then move parts sequence to match with the manufacture sequence, add parts required to the process, and remove meaningless intermediate modules or newly insert modules which are necessary to be separated. Parts subject to creation, modification and/or deletion in the course of transforming into mBOM should be individually managed for their history. Figure 9 shows the making process of mBOM from eBOM as follows: a) eBOM made in design stage, b) the basic mBOM automatically transformed from the eBOM, c) editing the basic mBOM with users knowhow and experience, and d) final mBOM completed.



a) eBOM b) Basic mBOM transformed from eBOM

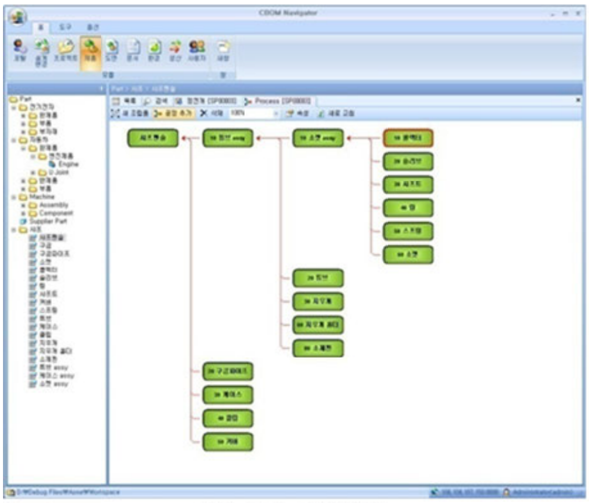
c) Edit mBOM with users' interaction d) Final mBOM

Figure 9. Main functions of mBOM management

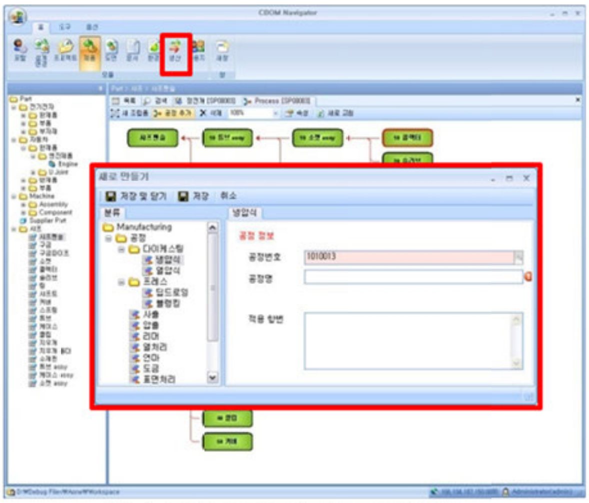
4.3 Management Module of process BOM

The pBOM-dedicated management module lays its purpose on the management of both manufacturing process as to each parts and assembly process as to multiple parts by using mBOM such as Figure 10-

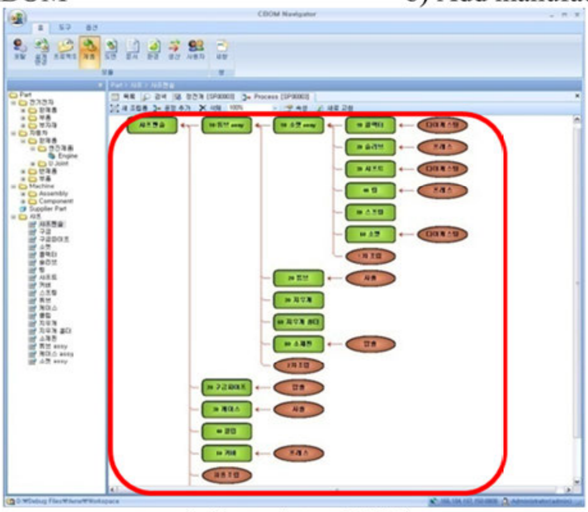
a). In particular, the inspection process may be selectively added to verify quality in the aspects of manufacturing and assembly processes. Provided one part or module is put into completion via a series of production processes, those processes are created according to the manufacturing sequence as shown in Figure 10-b). Newly registered process information relates to the management of individual attributes and history in a separate production module. Of course, it is also possible to select existing process information registered and connect it for use to pBOM. Figure 10-c) shows an example of pBOM which not merely changes the structure of mBOM but extends the concept of mBOM including the information on production process, assembly process and process parts.



a) Load mBOM



b) Add manufacturing process



c) Complete pBOM

Figure 10. Main functions of pBOM management

5. Conclusion

In light of the fact that a bill of materials (BOM) is categorized diversely depending on its structural aspect and usage aspect, the present study focuses mainly on the BOMs in view of usage; that is, eBOM, gBOM, mBOM and pBOM out of BOMs utilized throughout the product lifecycle. The eBOM systematically articulates upstream or downstream hierarchical assembly relationship between parts and end products from the product's functional viewpoint, being normally created in the phase of product design. The gBOM is developed by linking material information with parts constituting an end product with an outlook to effectively responding to the international environmental regulations. The mBOM structurally figures out the assembly relationship of parts by taking manufacturing sequence and methods into account, being transformed from eBOM but having a structure quite different from it by adding parts and intermediate modules required in the production phase. The pBOM includes process information as to detailed processes in addition to the concept of mBOM, which is devised aiming for integrated management of production information and process information.

This study initially defines gBOM and pBOM based on existing eBOM and mBOM and grasps understanding of differences among BOMs. Based on output gained from such literature research, the study attempted to design a modeling to support BOM-to-BOM transformation. In consequence, the study successfully designed and implemented a BOM-centric product data management system capable of managing aforesaid four typical types of BOMs and helping make their transformation to be made easily in accordance with in-field demands. In addition, the study applied the implemented prototype system to a few cases actually to know more about usefulness and effectiveness of the system.

Resulting from applying the developed BOM-centric PDM system to diverse cases in reality and successfully commercializing it, the system modeled herein is proven so reliable and effectively useful. Despite the foregoing, further researches to enhance its usefulness must be undertaken in the future by continuously converging the requirements of users and reflecting them to the system. In this sense, it is needed to enter into research to enlarge the scope of application by including to the BOM-centric PDM system, let alone aforementioned 4 types of BOMs, other various types of BOMs and transformation information as might be demanded in the product planning phase and post-production phases.

Acknowledgement

This paper is supported by Manufacturing service platform project funded by the Ministry of Trade, Industry and Energy (MOTIE) of Korea. The authors would like to thank for their support.

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