

A Closed-Loop Design Change Control Workflow in Product Data Management for Conceptual Design Phase

Jiun-Yan SHIAU and Xiangyang LI

Abstract—Product data management is an engineering oriented information system. Engineering change request, engineering change notice, and engineering change control workflow in a product data management system are usually utilized starting from the detail product design phase. Lack of guidelines to identify configuration items and design change control workflow is one of the major reasons for not using product data management system during conceptual design phase. In this paper, a conceptual design configuration framework is proposed, and a closed-loop design change control workflow is developed for applying product data management to conceptual design phase. The proposed approach has been implemented and tested for a steel foundry. The production planning activities of the foundry can therefore get involved sooner to the conceptual design phase. This work enables early involvement of the strategy in concurrent engineering during new product design.

Index Terms—Change Control Workflow, Product Data Management, Conceptual Design, Configuration Management

1. INTRODUCTION

Product data management (PDM) is defined as the classification of design information and specifications for a product, and the management of changes to such information. PDM systems first appeared in the 1980s [2]. The early PDM systems were effective in the engineering domain, but failed to encompass non-engineering activities, such as sales, marketing, and supply and customer management. With development of newer information technologies, web-based PDM systems were introduced and better accessibilities to suppliers and customers were provided. PDM, however, was still confined to engineering information management [2]. Stark (2005) surveyed the usages of PDM and PLM (product lifecycle management) throughout a product's

lifecycle, with the product design stage normalized to 100 percent (see Figure 1). This survey also showed the confinement. The trend of PDM is expected to focus on product lifecycle stages in general, an improved support of engineering collaboration functionality [1], and conceptual design processes [10]. Conceptual design is in the early stage during product development. Nagl et. al. (2003) pointed out that up to eighty percents of the life-cycle costs of a product are determined during this stage, even though conceptual design activities only account for around ten percents of the new product development. Conceptual design requires processing information from diverse sources in order to define the functional requirements, operating constraints, and evaluation criteria pertinent to accomplishing a prescribed goal [12]. During the brainstorming of conceptual design activities, those design related data keep changing and require maintenance. A PDM system just forfills for such purpose.

Configuration management (CM) is the theory behind a PDM system. CM was first introduced by US Department of Defense in 1992 [7]. It is a discipline applying technical and administrative direction, and a surveillance over the life cycle of configuration items to:

- Identify and document the functional and physical characteristics of configuration items (CI's);
- Control change of CI's and their related documentation;
- Record and report information needed to manage CI's effectively, and the status of the proposed and approved changes;
- Audit CI's to verify conformance to documented requirements.

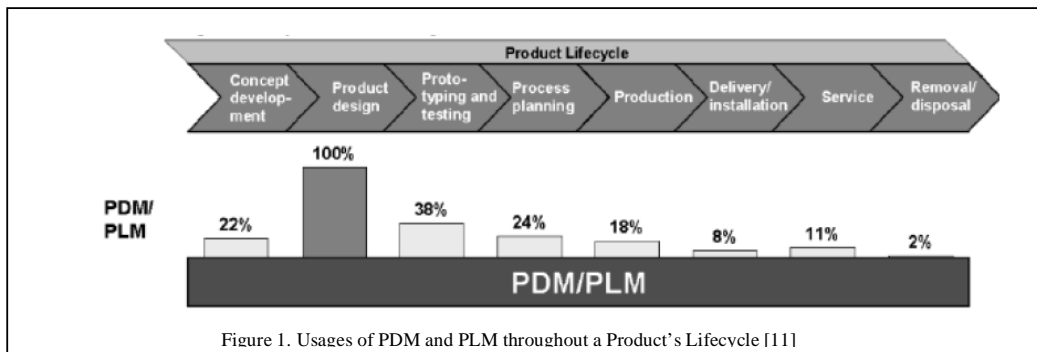


Figure 1. Usages of PDM and PLM throughout a Product's Lifecycle [11]

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Certain type of working forms such as ECR (enterprise change request) and ECN (enterprise change notice) are commonly used in the configuration management. These forms serve two purposes in the configuration management process.

- To provide authorization to do the work; and
- To provide a historical record and proof of conformance.

The Institute of Configuration Management (2002) described a closed-loop change control process (see Figure 2) to support corrective actions for deficiencies in customer requirements and therefore continuous improvement of product development.

closed-loop design change control workflow for the purpose of continuous improvement of conceptual design.

A generic design change control workflow for PDM utilized in conceptual design phase is therefore proposed in this paper. The remainder of this paper is organized as follows. In section 2, we review literatures on conceptual design approaches and processes and the closed-loop change control workflow. The proposed closed-loop

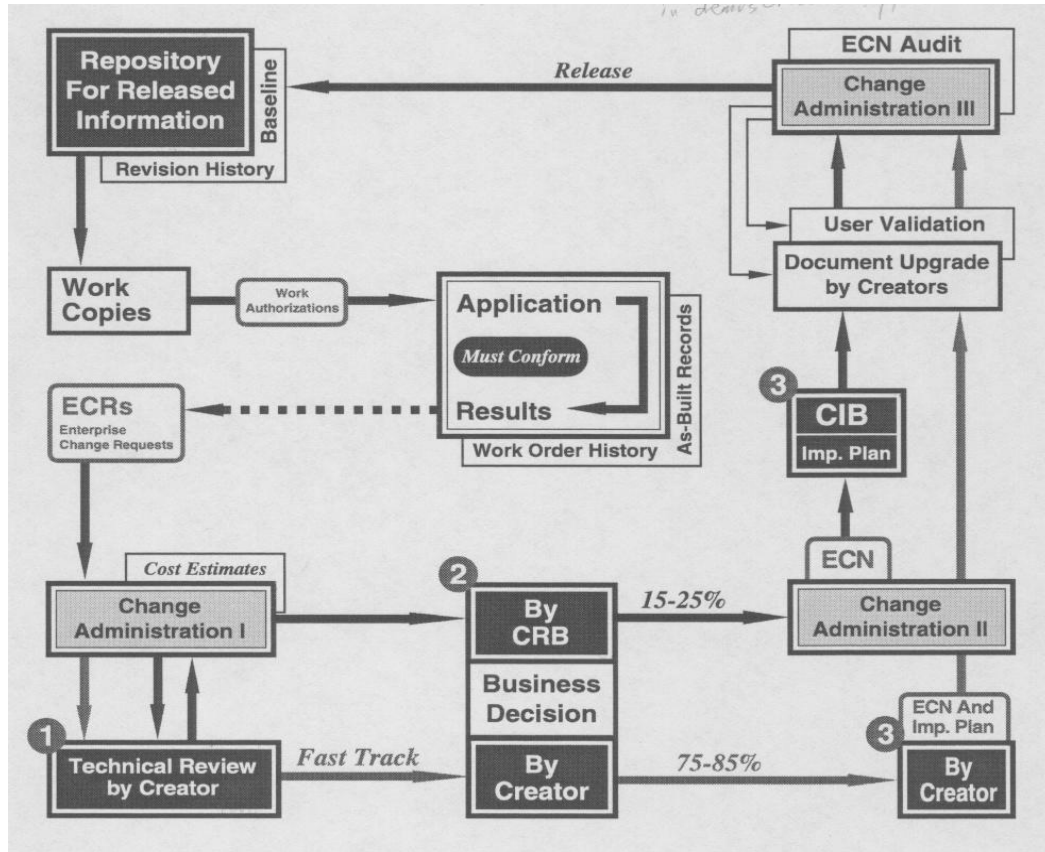


Figure 2. Closed-loop Change Control Process (ICM, 2002)

The change control process is launched while the first edition of manufacturing bill of materials (MBOM) is generated and recorded in the repository. Due to continuous changes in production engineering in nature, and inevitable errors and changes in products, ECR is not avoidable during the whole product lifecycle. Engineering change control is designed for in-time feedback from production phase to product design phase. A common misunderstanding of this change control model is to launch engineering change management during the conceptual design phase.

DCR (design change request) and DCN (design change notice) are the forms designed to give in-time feedback from conceptual design phase to production phase and service phase. These are opposite to the directions of feedback of engineering change control. Although DCR and DCN forms are similar to ECR and ECN forms, the closed-loop change control workflow is no longer suitable for design changes. Therefore there is a need to develop a

design change control workflow is presented in section 3. Section 4 presents a case study of a module implemented with design change control workflow. In the final section, we summarize our study, discuss the limitation, and suggest future researches.

2. LITERATURE REVIEW

2.1 Conceptual Design Process

Conceptual design is the phase where engineering science, practical knowledge, production methods, and commercial aspects needs to be brought together, and where the most important decisions of the product lifecycle are made. Design methods can prompt ways to tackle problems which otherwise might not be hit upon or, more probably, hit upon so late that the work they would have saved has already been wasted [5]. According to French's classification, there are five types of conceptual

design approaches, i.e. reduction of step size, prompting of inventive steps, generation of design philosophies, increasing the level of abstraction, and design and the computer.

There is no standard conceptual design process defined. Perhaps this is because conceptual design process is not deterministic; indeed it is stochastic. Here we will review the existing conceptual design processes proposed by academic researches.

The Systematic Approach to engineering design proposed by Pahl and Beitz (SAPB) was developed in the 1970s. SAPB divides the conceptual design process into a number of phases (see Figure 3). The steps between the phases are approximate and are based on iteration and recursion [4].

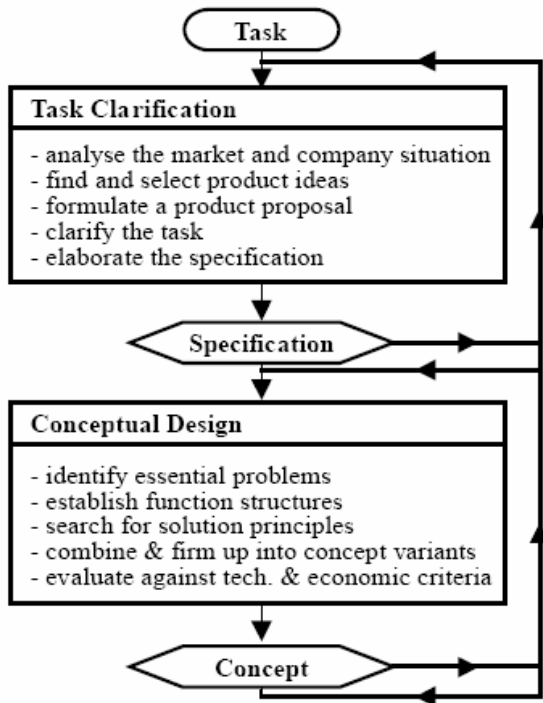


Figure 3. Conceptual Design Process of Pahl and Beitz (Redraw after [4])

The first phase addresses the clarification of the design task to be performed, involves collection of the requirements and constraints information that the product should meet, and elaborates the specification. The second phase is that of the conceptual design that starts by an analysis of the specification in order to identify the essential problems to be solved. The design problem is then formulated in an abstract, solution-neutral form. This makes the solution space as wide as possible. The problem may then be decomposed into sub-problems and sub-functional structures to the problems may then be established. Solutions to the sub-functional structures are then sought. Afterwards, promising system solutions are further developed into concept variants. Finally, use-value analysis is used to evaluate the concept variants, and the “best” concept is selected for further development.

Brunetti and Golob (2000) expanded the conceptual design model proposed by Pahl and Beitz, in task

clarification, determination of functions and structures, search for solution principles and their structures (see Figure 4) further into more details. The difference between the model in Figure 3 and this model is determination of functions and structures is separated from the conceptual design phase in order to search for functional modules/structures that can be applied for the best concept.

Zuo (2000) presented a conceptual design architecture including three modules of problem definition, issue resolution, and conceptual formation, as shown in Figure 5. The bi-directional transition links within each cycle, as well as between each pair of cycles, indicate design iterations.

Problem definition generates a problem description (i.e. a specification of the desired behavior), a set of requirements (i.e. the performance that the object under design must meet by the time the design is completed), and/or a set of design constraints (i.e. the condition with which the designer must comply). After the problem is defined, consultation with professionals may be necessary to find out the actual issues for the design. It is a decision-making process that involves choosing one or more options or an open design issue. Design knowledge is crucial for making sound decisions during this phase; oftentimes new knowledge is gained during this exploratory stage.

Concept formation results in either a pseudo description or a schematic diagram at a specified abstract level. It does not have to be as detailed as a formal design specification. During concept formation, the designer may go back to the problem definition stage to modify/review the problem specification, or to the issue resolution stage to solve previously deferred issues, identify additional issues, or change previous decisions. Afterwards, an automatic program can be invoked to update the decision plans based on the current decisions. The designer can then continue with his/her previous concept formation work until a satisfactory conceptual design description is determined.

Austin et al (2001) extended the previous literature to construct conceptual design process as two phases (see Figure 6). One is “develop business need into design strategy”, and the other is “develop design strategy into concept proposal”. The design strategy phase could be decomposed into two stages. The two stages are “interpret”, which is used to find out the essential problems, and “develop”, which is used to determine project characteristics. The developing concept strategy phase could be decomposed into three stages: (1) diverge, which is used to search for possible solution principles, (2) transform, which is used to firm up into concept variants and (3) converge, which is used to evaluate and choose alternatives.

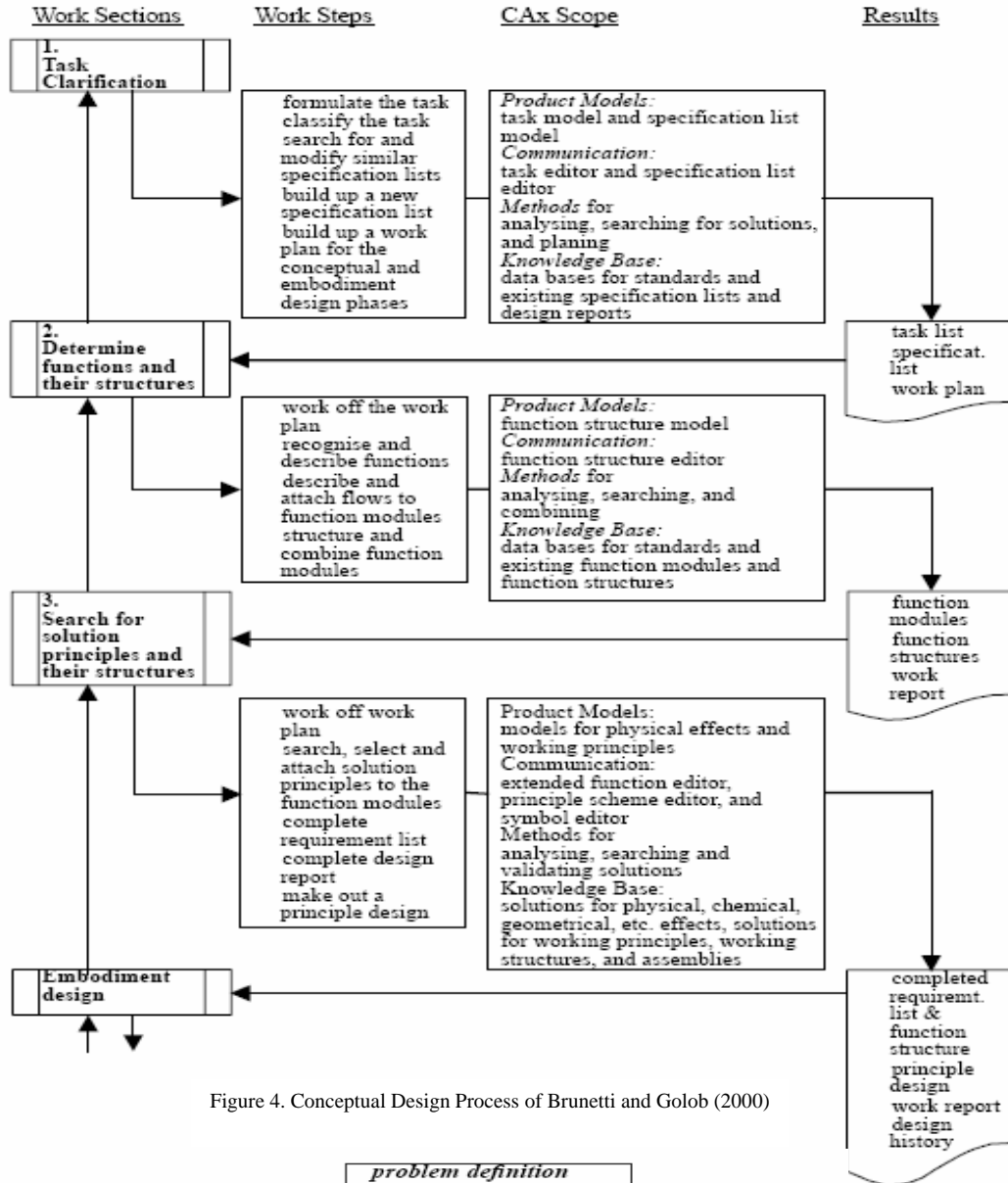


Figure 4. Conceptual Design Process of Brunetti and Golob (2000)

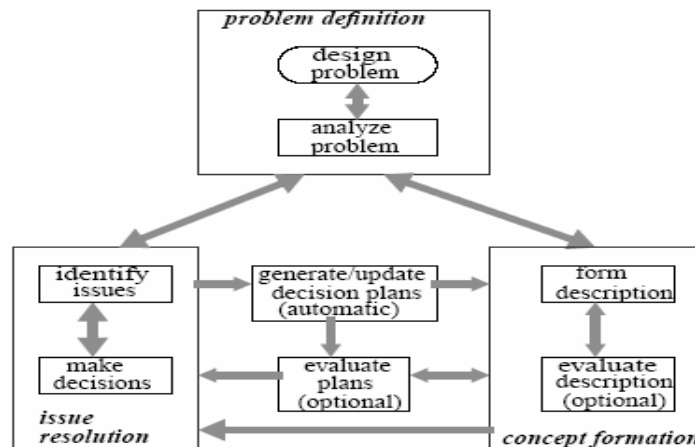


Figure 5. Conceptual Design Process of Zuo (2000)

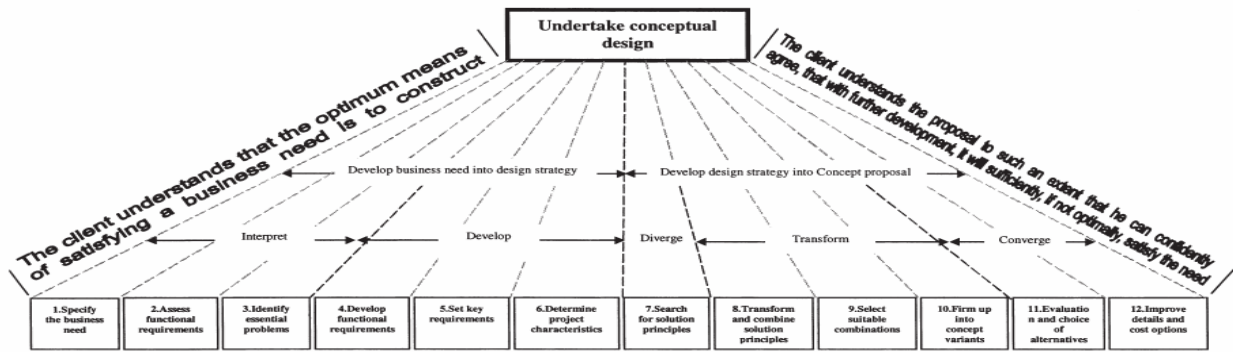


Figure 6. Conceptual design process of Austin et. al. (2001)

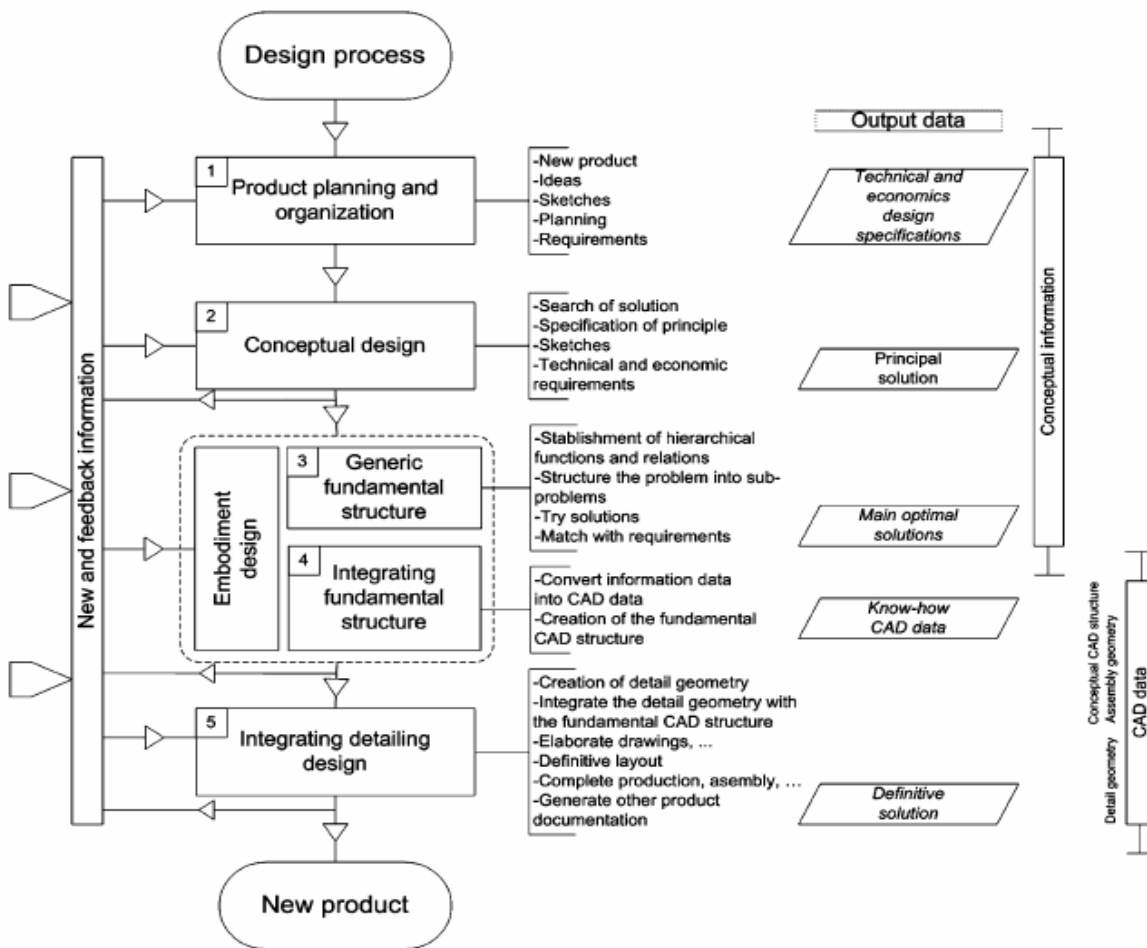


Figure 7. New Product Design Process of Nuria et. al. (2004)

Nuris et. al., (2004) proposed a top-down conceptual design process including the following phases to maximize production efficiency for a new product (see Figure 7):

- Earliest product planning and organization.
- Establishment of the product conceptual design.
- Arrangement of specification principle into a hierarchical-functional structure.

There are various kinds of conceptual design process described above. Some of them divided conceptual design process into several steps, and others described the structure of conceptual design process. We try to compare these conceptual design processes to summarize a generic conceptual design process as the table below.

Table 1: The Comparison of Conceptual Design Process

Generic conceptual design	Austin et al. (2001)	Pahl and Beitz(1970)	Brunetti and Golob(2000)	Zuo (2000)	Nuris et al. (2004)	
<ul style="list-style-type: none"> ◆ Analyze the market and company situation ◆ Find and select product ideas ◆ Formulate a product proposal ◆ Clarify the task 	<ul style="list-style-type: none"> ◆ Specify the business need 	<ul style="list-style-type: none"> ◆ Analyze the market and company situation ◆ Find and select product ideas ◆ Formulate a product proposal ◆ Clarify the task 	<ul style="list-style-type: none"> ◆ Formulate the task ◆ Classify the task 	<ul style="list-style-type: none"> ◆ Problem definition 	<ul style="list-style-type: none"> ◆ New product ◆ Ideas 	
<ul style="list-style-type: none"> ◆ Search for and modify similar specification lists ◆ Build up a new specification list 	<ul style="list-style-type: none"> ◆ Assess functional requirements 	<ul style="list-style-type: none"> ◆ Elaborate the specification 	<ul style="list-style-type: none"> ◆ Search for and modify similar specification lists ◆ Build up a new specification list 		<ul style="list-style-type: none"> ◆ Sketches ◆ Planning ◆ Requirement 	
<ul style="list-style-type: none"> ◆ Identify essential problems 	<ul style="list-style-type: none"> ◆ Identify essential problems 	<ul style="list-style-type: none"> ◆ Identify essential problems 	<ul style="list-style-type: none"> ◆ Build up a work plan for the conceptual and embodiment design phase 	<ul style="list-style-type: none"> ◆ Issue resolution 		
<ul style="list-style-type: none"> ◆ Develop functional requirements 	<ul style="list-style-type: none"> ◆ Develop functional requirements 	<ul style="list-style-type: none"> ◆ Establish function structure 	<ul style="list-style-type: none"> ◆ Work off work plan 			
<ul style="list-style-type: none"> ◆ Set key requirements 	<ul style="list-style-type: none"> ◆ Set key requirements 		<ul style="list-style-type: none"> ◆ Recognize and describe functions 			
<ul style="list-style-type: none"> ◆ Describe and attach flows to function modules ◆ Structure and combine function modules 	<ul style="list-style-type: none"> ◆ Determine project characteristics 		<ul style="list-style-type: none"> ◆ Describe and attach flows to function modules ◆ Structure and combine function modules 			
<ul style="list-style-type: none"> ◆ Transform and search for solution principles 	<ul style="list-style-type: none"> ◆ Search for solution principles 	<ul style="list-style-type: none"> ◆ Search for solution principles 	<ul style="list-style-type: none"> ◆ Work off the work plan 			<ul style="list-style-type: none"> ◆ Search of solution ◆ Specification of principle
<ul style="list-style-type: none"> ◆ Combine solution principles 	<ul style="list-style-type: none"> ◆ Transform and combine solution principles 	<ul style="list-style-type: none"> ◆ Combine & firm up into concept variants 	<ul style="list-style-type: none"> ◆ Search, select and attach solution principle to the function modules 			<ul style="list-style-type: none"> ◆ Sketches
<ul style="list-style-type: none"> ◆ Select suitable combinations 	<ul style="list-style-type: none"> ◆ Select suitable combinations 					<ul style="list-style-type: none"> ◆ Technical and economic requirements
<ul style="list-style-type: none"> ◆ Evaluation and choice of alternatives 	<ul style="list-style-type: none"> ◆ Firm up into concept variants 					<ul style="list-style-type: none"> ◆ Establishment of hierarchical functions and relations
	<ul style="list-style-type: none"> ◆ Evaluation and choice of alternatives ◆ Improve details and cost options 	<ul style="list-style-type: none"> ◆ Evaluate against technology & economic criteria 	<ul style="list-style-type: none"> ◆ Structure the problem into sub-problems ◆ Try solutions ◆ Match with requirements 			
<ul style="list-style-type: none"> ◆ Complete design report 			<ul style="list-style-type: none"> ◆ Complete requirement list ◆ Complete design report ◆ Make out a principle design 			<ul style="list-style-type: none"> ◆ Conceptual formation

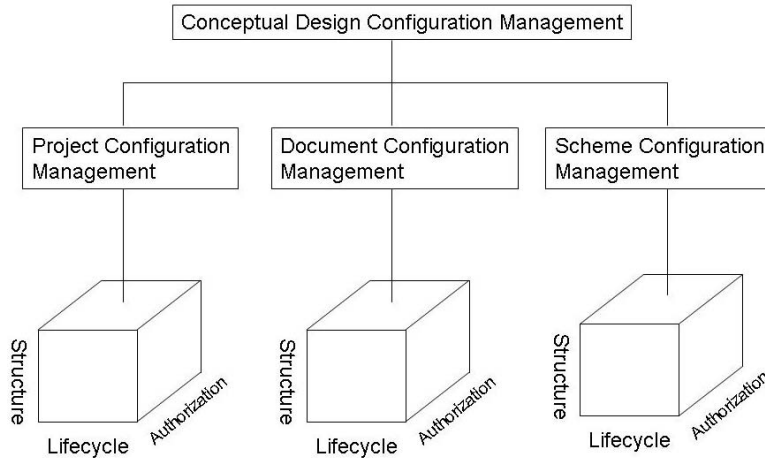


Figure 8. Conceptual Design Configuration Management Architecture

2.2 PDM and Closed-loop Change Control Workflow

PDM system is an implementation of configuration management (CM) theory. The Institute of Configuration Management (2002) described a closed-loop change control process (see Figure 2) within the CMII (configuration management II) principles. In addition to the CM principles, CMII shifts the emphasis of CM to (1) accommodate change, (2) accommodate the reuse of standards and best practices, (3) assure that all requirements remain clear, concise and valid, (4) communicate (1), (2) and (3) to each user promptly and precisely and (5) assure conformance in each case. As shown in Figure 2, an enterprise change request (ECR) is provided and passed to Change Administration I, when a document in the baseline is intended to be changed. ECR is the type of document that records what to change, the reason to change and the priority of changes. Change Administration I accepts or denies the ECR based on the results consulted from professionals in charge with each configuration item. Accepted ECRs are then passed to change review board (CRB) or original creators for approval and then for making business decision based on further discussion in CRB meetings. Approved ECRs are organized as enterprise change notices (ECNs) by Change Administration II. ECN is a document recording how to change and when to change. Change implementation board (CIB) is held by Change Administration II for planning the detail of ECN implementations. Finally, Change Administration III audits the consistencies of ECNs, releases the revised documents, and updates new states to the baseline.

3. CONCEPTUAL DESIGN CONFIGURATION AND CLOSED-LOOP DESIGN CHANGE CONTROL WORKFLOW

To introduce the closed-loop design change control framework proposed by us, as the basis we will first

describe the structure to decompose a conceptual design phase. After that we elaborate the different components in the structure and their requirements in configuration management. Thereafter very naturally we present the new change control framework.

3.1 Conceptual Design Configuration

The products of the conceptual design phases are called schemes [5]. A scheme means an outline solution to a design problem, and it carries to a point where the means of performing each major function has been fixed, as have the spatial and structural relationships of the principal components. A scheme should be detailed and worked out for it to give approximate costs, weights, and overall dimensions, and with circumstances allowed to be as practicable as possible. With already established practice, a scheme should be relatively explicit about special features or components, but need not to go into much detail. This is the phase where the most important decisions are made based on combined aspects of engineering science, practical knowledge, production methods, and commercial.

To identify the configuration items, we have to take a look at the lifecycle of schemes. The data created through the scheme lifecycle are related to projects, documents and schemes. The project related data included quality, scheduling, and costs. The documents could be presented in drawings, forms, and reports. The schemes related data are such as functional solutions, non-functional solutions, and usability solutions. As shown in Figure 8, conceptual design configuration management consists of project configuration management, document configuration management, and scheme configuration management. Each of them is organized in three dimensions, lifecycle, structure, and authorization.

An object in project configuration, document configuration, or scheme configuration is called configuration item. The structure dimension includes

Department, Attribute, Document Link, Scheme Link, Project Link, Content Class, and Version of an object. The authorization dimension includes Function Authorization, Department Authorization, and Lifecycle Authorization of an object. The lifecycle dimension (see Figure 9) includes New, Approve, Release, Frozen, Delete, and Scrap of an object. Lifecycle, structure, and authorization are the three control and management dimensions applied to each configuration item in conceptual design configuration management.

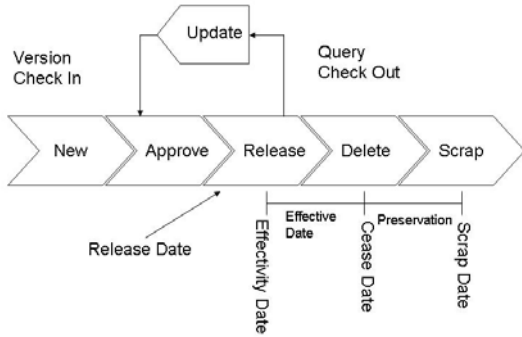


Figure 9. Phases of the Lifecycle Dimension

3.2 Document Lifecycle Workflow

In a new product development project, documents for conceptual design are created after receiving the new project assignment. Designers create various documents, for example, customer requirements, for references to each related department. Designers are approved to create or modify documents. Those documents signed by related personnel and approved by high level administrators, are managed within a document management center. The effectivity dates (as shown in Figure 9) for each document are assigned and accessibilities to the documents are given.

A deleted document will be preserved for a certain period of time, and then finally be scrapped from history. The above described is the lifecycle of a document (see Figure 10).

3.3 Scheme Lifecycle Workflow

In this research, we summarized those conceptual design activities, as described in literature review, as a generic conceptual design workflow. The conceptual design workflow starts with the requirement collection activity. The scope of this activity is to collect related information of customer requirements and to check the project boundary. Problem description activity follows the requirement collection activity. The scope of the problem description is to try to mince the expecting product, i.e., to divide the product into several tasks and describe each task clearly according to professions and experiences. It also describes the problem definition to customers and gets the approval. A new design project approved by the marketing administrator is therefore formed. The product characteristics, which are functional requirements based on the product descriptions, are then produced. A new project along with a new product design proposal is formed and requires the approvals from the customer and the marketing administrator. Designers will then discuss and generate schemes to resolve those product characteristics.

While the first edition of design scheme is generated, it becomes a baseline and will be stored as a type document in the document management center, which is one module in a PDM system. In order to continue to improve the design scheme, designers may keep brainstorming and generate alternative new schemes to replace the old. Each alternative or replacing new design scheme should be managed within the document management center.

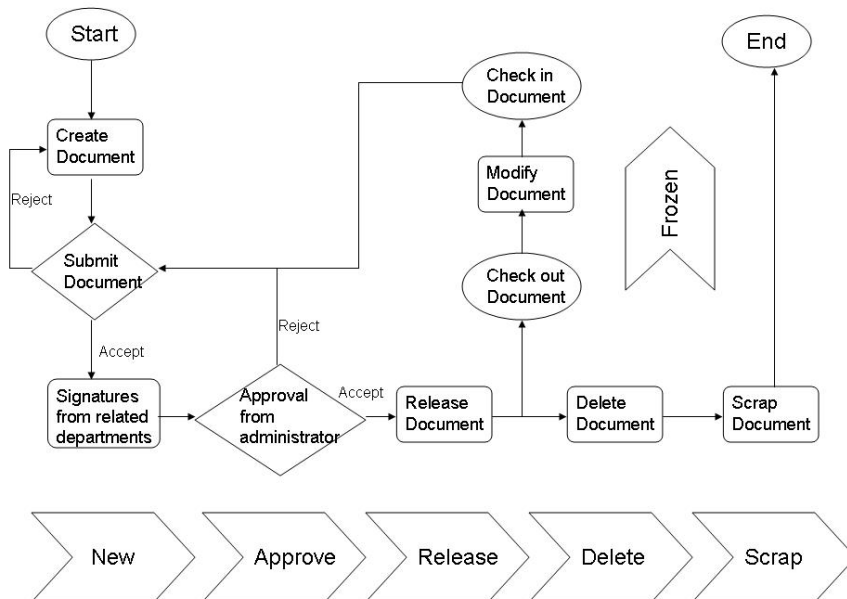


Figure 10. Illustration of the Document Lifecycle

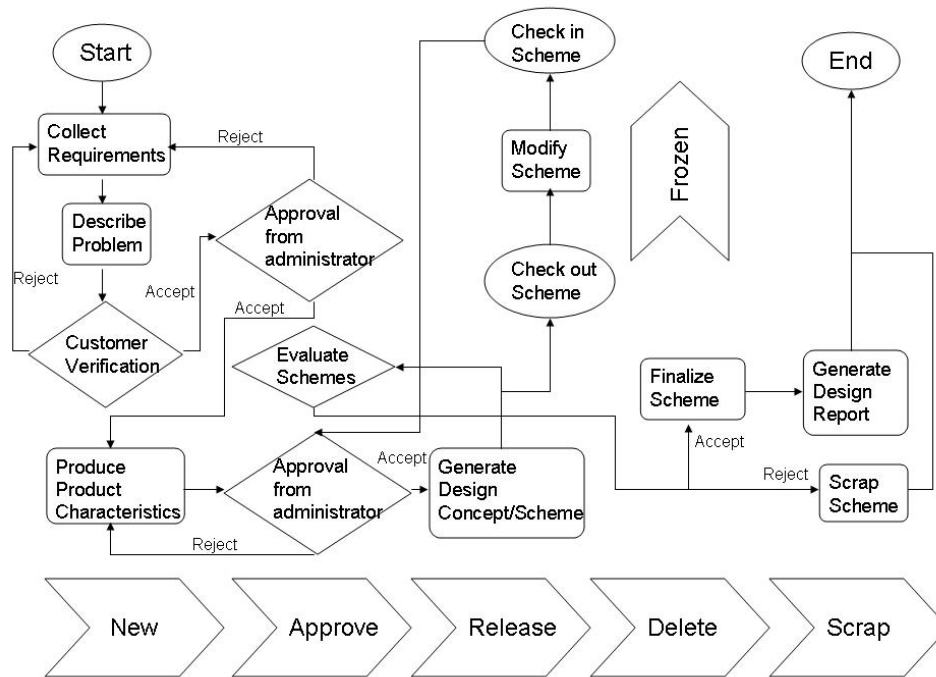


Figure 11. Scheme Lifecycle

Scheme evaluation activity then follows in place. If a near-optimum design scheme exists, the scheme finalization activity is applied. A design report for the next phase, detail design, is generated. The other rejected design schemes are then scrapped. The mapping between the scheme lifecycle and the generic conceptual design workflow is as shown in Figure 11.

3.4 A New Closed-loop Design Change Control Workflow

Before go in depth with the closed-loop design change control workflow, we will briefly discuss the early involvement strategy in concurrent engineering. Concurrent engineering is one of the engineering approaches widely applied to new product development. One of the most important strategies in concurrent engineering is early involvement. The solution of early involvement is to pass the information in-time from the supplier to the client. The benefits and purposes of early involvement are to:

- Early discovery of the product deviation
- Consider the stock on hand during conceptual design phase
 - Reduce the possibility of engineering changes during production phase
 - Create standard product data
 - Create standard product specification
 - Create standard operation process
 - Create unified semantics

Therefore it is obvious that a new closed-loop design change control workflow is needed and will be able to

benefit the early involvement of different departments in conceptual design in general. This closed-loop change control is different from the model described in previous sections in two essential aspects:

- The “feedback” here is a forward notification mechanism that goes from the upstream conceptual design to downstream activities including detailed design, production planning, etc. Such changes are mostly useful when they occur at the early development stages of a product, i.e. when most efforts are spent in conceptual design.

- The working forms or messages and their functions are, largely due to the above difference, very different from the ECR and ECN. In this sense these forms should function more as active triggers rather than passive responses. This requires special attention to the control and synchronization of the lifecycle, authorization and structure workflows in terms of project, document and scheme configuration management.

There are two scenarios of design change. One is to modify an existing design and the other is to recognize shortcomings in a nearly completed design. No matter which scenario of design changes, it will affect downstream activities. For example, the product is unable to be manufactured due to the design changes or the new material is too costly due to the design changes.

The purposes of the proposed closed-loop design change control workflow are to ensure the continuous improvement of generate conceptual schemes, and to enable the consideration of stock on hand, and/or manufacturability of design during conceptual design phase. In order to ensure the continuous improvement of

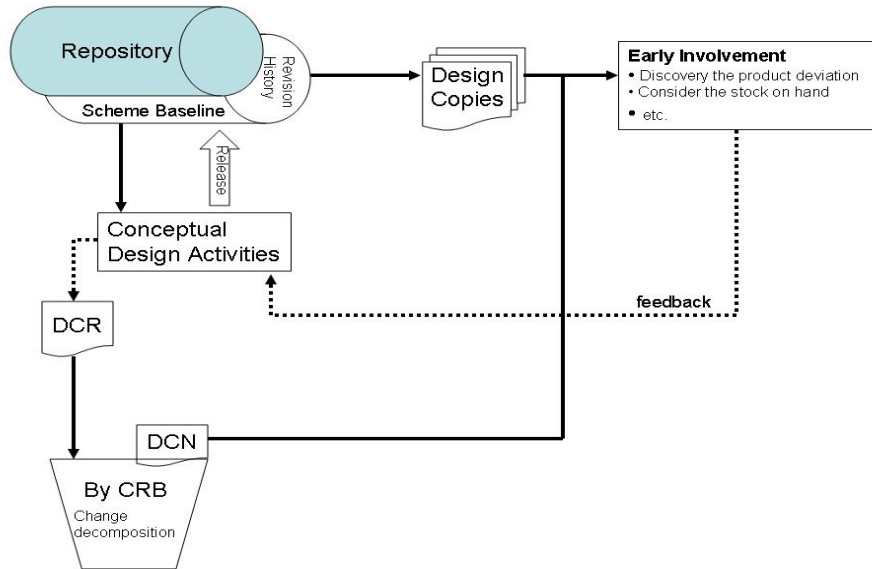


Figure 12. A New Closed-loop Design Change Control Workflow

schemes, a scheme baseline should be stored in the repository of document management center. For example, at least three conceptual schemes should be recorded in the scheme baseline, one candidate design scheme, and two other alternative design schemes. At each periodic scheme evaluation, either alternative design scheme is possible to become the candidate design scheme. Better conceptual scheme is encouraged to be generated among the movements of alternative design schemes and candidate design scheme.

Finally the proposed closed-loop design change control workflow is illustrated as Figure 12. Whenever a new candidate design scheme is chosen from candidate design schemes, a DCR form should be filled. A DCR is submitted to the change request board (CRB). A DCR form differs from an ECR form. A DCR form is filled in conceptual design phase; however, an ECR form is filled in production phase. Different from the change control workflow for engineering changes, the CRB here is to decompose the content of DCR into several DCNs based

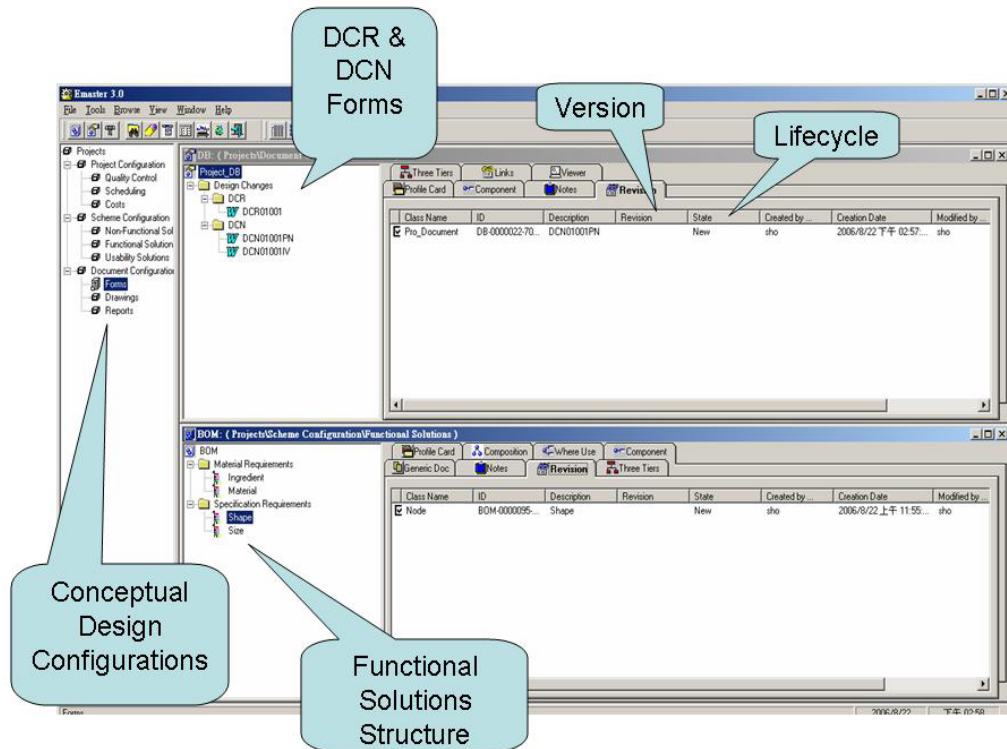


Figure 13. Conceptual Design Configuration in a PDM System

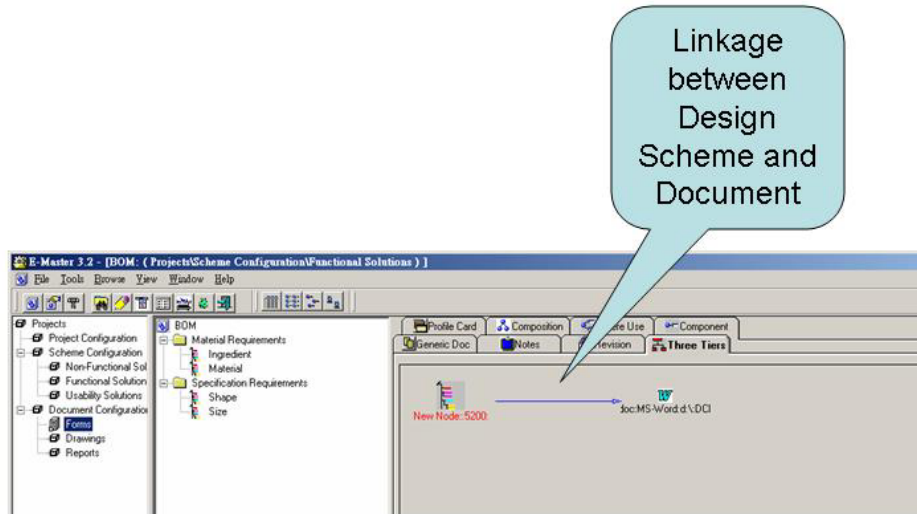


Figure 14. Linkage between Design Scheme and Document

on conceptual design configuration. Those DCNs are delivered to related departments, such as production planning department, for early involvement purpose. If there is no significant feedback of defects from those DCN receivers, a new candidate design scheme is released into the repository.

Please notice that this is just a conceptual illustration of a generic closed-loop design change control workflow while detailed and complete processes and controls are still ongoing efforts. However we will describe a prototype system based on this framework and a brief introduction of a case study following that in the next section.

4. IMPLEMENTATION

The system implementation takes into account the major aspects discussed in the previous sections. The conceptual design configuration and closed-loop design change control workflow have been developed. A commercial PDM system and a commercial workflow system have been used to create conceptual design configuration and design change control workflow respectively. An integration of these two commercial software fulfills the promise of utilizing PDM in conceptual design phase. The details are as follows:

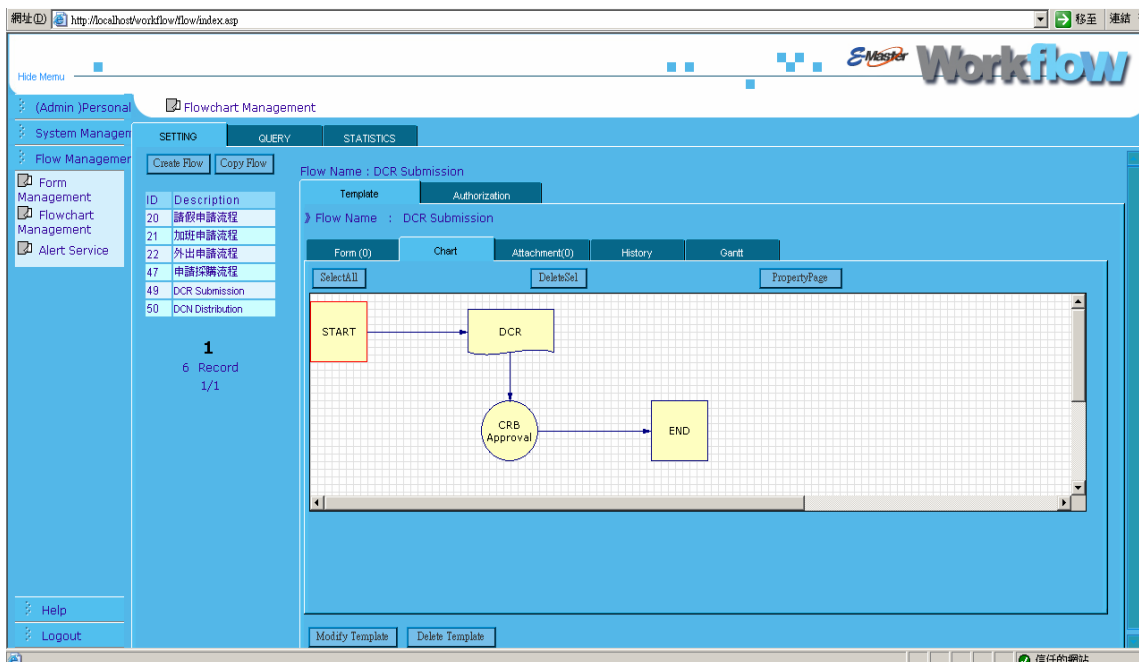


Figure 15. DCR Submission Workflow

As shown in the left frame of Figure 13, a conceptual design project contains project configurations, scheme configurations, and document configurations. Two dimensions, lifecycle and structure, are expanded in the right frames of Figure 13. Designers and authorized users can upload any type of design documents by drag and drop. The linkage between a design scheme in the design scheme structure and a design document is illustrated in Figure 14. Designers and authorized users can extract design data through design scheme aspect, document classification aspect, or project management aspect. The DCR and DCN forms and their history are also recorded in this system.

Jin Chia Industrial Co. Ltd. It is a steel foundry in southern Taiwan. The company produces stern frame, winch M/C, anchor, and rudder carrier for marine use. The electric arc furnace runs at night twice a week for energy saving purpose, therefore the planning and scheduling of raw materials to the arc furnace is relatively important. With the proposed system, the company can plan the purchasing of different types of raw materials during the conceptual design phase. The early involvement strategy does increase the accuracy of material planning. However, the performance is still under close studying.

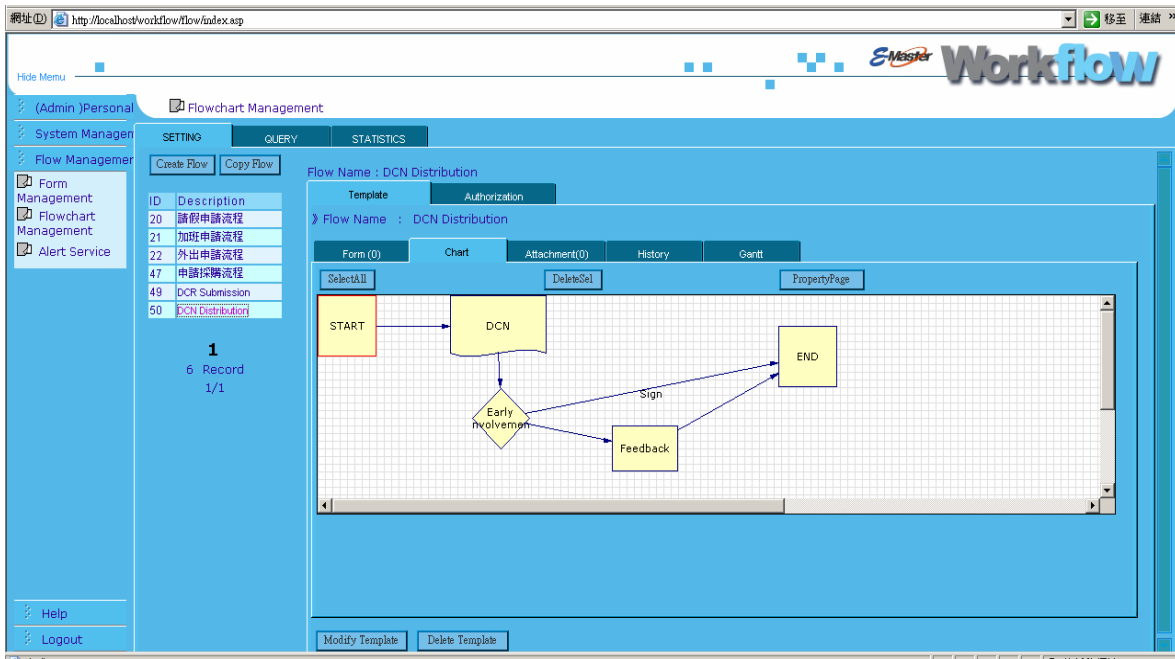


Figure 16. DCN Distribution Workflow

The new DCRs and DCNs are distributed to correlated persons through the design change control workflow, implemented as shown in Figure 15 and Figure 16. The workflow system utilized in this project is a form driven system. Each workflow considers one open-ended workflow of a specific form. Since the closed-loop design change control workflow contains two different forms, two open-ended control workflows would fulfill its implementation. As shown in Figure 15, a DCR submission workflow is developed for designers to submit a DCR form to CRB. At the end of DCR submission workflow, the DCR form is stored into the PDM system.

The other open-ended workflow is called DCN distribution workflow as shown in Figure 16. A DCN distribution workflow is developed for CRB members to distribute the DCNs to related persons or departments. At the end of DCN distribution workflow, the DCN forms are also stored into the PDM system.

The proposed conceptual design configuration and closed-loop change control workflow have been tested to

5. CONCLUSION

One of the major reasons that a PDM system has been less popular to conceptual design phase is the lack of conceptual design configuration and design change control workflow. The presented work fulfills the first two phases of configuration management, i.e., identify configuration items and change control. The proposed conceptual design configuration framework provides a guideline to identify the configuration items in conceptual design phase. The proposed closed-loop design change control workflow controls the changes in configuration items and their related documentation, and maintains the consistency among documents for the purpose of continuous design improvement.

The presented work enables the early involvement strategy such as in concurrent engineering. Various departments, such as production planning department, can get involved earlier in the conceptual design phase. Rather than enabling the in-time backward feedback from

production phase to product design phase, this work enabled the in-time forward feedback from conceptual design phase to production phase.

This work has been implemented as two separate systems in our prototype system. The DCR and DCN forms submitted to the design change control workflow have to be uploaded to the PDM system manually. Also, the approval procedure in the workflow system has to be done again in the PDM system. Therefore integration between PDM system and workflow system is required in the future and the next focus will be the development of all necessary components and workflows in the proposed change control framework.

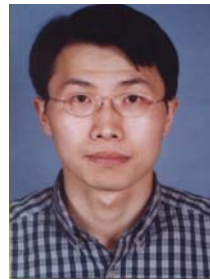
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