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Information model for engineering change management

Clifford L. Panokarren
Florida International University

FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

INFORMATION MODEL FOR ENGINEERING CHANGE MANAGEMENT

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by

Clifford L. Panokarren

2004

To: Dean Vish Prasad
College of Engineering

This thesis, written by Clifford L. Panokarren, and entitled Information Model for Engineering Change Management, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this thesis and recommend that it be approved.

Shih-Ming Lee

Joe Chow

Chin-Sheng Chen, Major Professor

Date of Defense: April 2, 2004

The thesis of Clifford L. Panokarren is approved.

Dean Vish Prasad
College of Engineering

Dean Douglas Wartzok
University Graduate School

Florida International University, 2004

DEDICATION

This thesis is dedicated to my parents, my sister and her two wonderful kids and to my committee members Dr. Chen, Dr. Lee and Dr. Chow. Without their patience, continuous and timely support, the completion of this work would not have been possible. This may be an appropriate tribute to all of them.

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ABSTRACT OF THE THESIS

INFORMATION MODEL FOR ENGINEERING CHANGE MANAGEMENT

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Clifford L. Panokarren

Florida International University, 2004

Miami, Florida

Professor Chin-Sheng Chen, Major Professor

Managing engineering changes is a critical task for organizations to remain competitive. In a manufacturing organization there are innumerable engineering change requests. This thesis is focused on the development of an information model that defines the engineering change process.

This research developed an activity model in IDEF0, an object model in IDEF1X and a dynamic model using state diagrams. The activity model captures the business process for executing an engineering change in terms of its constituting activities and sub-activities. The object model defines each object and its attributes identified in the activity model. The dynamic model captures the status change of each object in the engineering change process. This study concludes with a summary, implementation issues and future work that can be done in the direction of implementing a system based on the information model developed.

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LIST OF ACRONYMS

EC = Engineering Change.

ECRs = Engineering Change Requests.

ECM = Engineering Change Management.

ECN = Engineering Change Notification.

ECMS = Engineering Change Management System.

PD = Product Development.

EDMS = Engineering Data Management System.

ECO = Engineering Change Order.

CAD = Computer-aided-design.

CAECC = Computer-aided-Engineering-Change-Control.

OEM = Original Equipment Manufacturer.

ROI = Return on Investment.

PDM = Product Data Management.

BOM = Bill of Materials.

MRP = Materials Resource Planning.

CHAPTER

I INTRODUCTION

1.1 BACKGROUND

In order to be successful and competitive, companies not only have to entertain engineering change requests (ECRs) but also manage it efficiently. There is a belief that product design is more of inspiration than perspiration. But this rationale depends on the product type designed and the stage the design process has reached. In a manufacturing organization there are innumerable numbers of ECRs. These arise from various sources right from the ones initiated by the customers' change in specifications to the ones arising from a product design being unsafe.

1.1.2 Definition of Engineering Change

Huang et al (1999) define engineering changes as changes and modifications on forms, fits, materials, dimensions, functions and processes for the manufacture of a product or component. Chen et al (2002) define engineering change (EC) as a task by which companies request, implement and affect changes to products, documents, processes or even raw-materials. Wright (1997) defines ECs as modifications to a product, after the raw-materials have entered production. ECs can be as simple as changes in documentation related to the design of a product or they may be as complicated as an entire redesign of the entire product and its related manufacturing processes. Dec et al (1998) state that 'engineering change is a task by which companies request, implement and affect changes to products, documents, components, manufactured or purchased parts, processes or even supplies.' ECs have serious implications in any company because it could involve all the functions across the entire organization. Various functional departments of an organization may not only be the source but also the victims of an EC. Manufacturing companies have to constantly cater to ECs and constantly adjust their activities.

1.1.3 Need for Engineering Change

Competition in the market demands that companies develop and manufacture complex products with higher quality and lower price to stay competitive. The product life cycles have decreased significantly, which underline the importance to develop the products in a shorter time in order to maximize the market. The old sequential way of performing product development (PD) and produce large series of products is turning into production of customer variants with a fast adaptation to changing customer needs. This requires that the EC process be performed quickly. An increasing product complexity utilizing multiple technologies along with a shorter time for the PD makes it necessary to have more people with different competencies involved in each PD project. However, changes due to wrong decisions and changes in customers' requirements are unavoidable. The impact of any ECR has to be investigated. This also involves fluent flow of information related to the product and process items within all the affected departments.

1.1.4 Implications of ECs

Effective control over the management of engineering changes will facilitate proper execution of ECs especially in the terms of lead-time and costs incurred, thereby increasing profitability. Balcerak and Dale (1992) point out that inefficient control over ECs may result in adverse impacts which include effects on delivery time, production schedules, scrap, rework and low BOM accuracy. Huang and Mak (1996) have reported administrative costs pertaining to engineering changes to the tune of US $ 3.4-7.7 million and execution costs to 10 % of annual turnover. Engineering changes occurring frequently determine 70-80 % of the product cost (McIntosh, 1995).

1.1.5 Triggers of Engineering Change

Organizational, technological and operational changes are often causes for engineering changes (Huang and Mak, 1997). There are various kinds of ECRs that arise in an organization. ECRs may appear at various stages of the PD process. The possible causes of these ECRs are identified below:

- ECRs arising due to changes in customer specifications.
- ECRs arising due to faults in the transformation of customer needs into technical requirements.
- ECRs due to changes in customer needs.
- ECRs due to changes in architectural design.
- ECRs due to changes in component design.
- ECRs due to changes in process design.
- ECRs due to change in use of resources.
- ECRs arising due to difficulties in parts fabrication or assembly.

ECRs can also originate from different causes apart from the ones mentioned above. For example:-

- Change of a part depending on altered function or production requirement.
- Change in application of a part/component/subcomponent.
- Introduction / replacement/ withdrawal of a new part/component/ subcomponent.

1.2 Problem Statement

Management of engineering changes depends on the engineering process as well as management of information pertaining to the engineering process (Chen et al, 2002). There is a need for a structured and generic model to store, integrate, manage and control both the EC data and the EC process. Thus the problem statement can be stated as:-Lack of an information model to guide the EC process.

1.3 Objective

The prime objective of this research is to capture the EC process flow and data to guide the execution of engineering changes. Thus the information model should be able to facilitate the orderly and effective management of the EC process and the EC data. This objective is based on a set of criteria as stated below:-

The information model must have a process model which handles various types of ECRs arising in a manufacturing setting. The PD process has various stages. An ECR can arise at any of these PD stages. For example, when a product is in the fabrication stage, the customer can always come back and request for changes in product specifications. Therefore the criterion of the model is that it should be able to handle any type of ECR at any PD stage.

Managing engineering changes is a business process (Chen et al, 2002). A business process is composed of constituting activities that have to be executed. Capturing a business process in its logical activities greatly simplifies the execution of the business process. Thus the other criterion of developing this model is to capture the business process of managing engineering changes in its constituting activities. This paves the way to develop a generic EC model.

The EC process model must align itself with the concepts of process integration and information integration (information related to engineering changes). This can be achieved by the development of a detailed activity model which will streamline the essential functions and sub-functions necessary to plan and implement an EC.

The information model must consider reports and notifications generation like ECR, EC review reports and ECNs. It must capture all data entities (objects) in the EC process, their life cycle and define them in terms of their attributes so that tracking of these entities becomes easier for the participants of the EC process. It must align the EC process to the PD process so that the participants in the EC process get the flexibility to request an EC at any stage in the PD process.

1.4 SIGNIFICANCE

The significance of the information model can be discussed in terms of its possible uses. Since the information model (activity model) captures the business process of EC in terms of its constituting activities, it can be used to establish and identify the roles and responsibilities of all functional participants in the EC process. This information model can be used by manufacturing organizations as a blueprint to develop an ECM information system. In case of organizations that do not have the ability to develop an ECM information system this model can be used as a standard operating procedure for their EC process. The objects and their attributes from the object model can be used to define the forms like ECR, ECN and ECO. The dynamic model has captured the life cycle of critical objects (ECO, ECR and ECN) in the EC process. This will help to track the status of these objects in the EC process.

1.5 ORGANIZATION OF THESIS

The thesis is organized in 5 chapters. Chapter 2 reviews the literature in the field of ECM. Chapter 3 covers the development of the EC model starting with use case modeling to develop the activity model. After the development of the activity model, object modeling (IDEF1X) is done wherein all the objects of the EC process are identified and defined in terms of their attributes using object class diagrams and attribute tables. The dynamic model captures the dynamics of critical objects, their life-cycle and the state change in critical objects due to trigger of an EC event. Sequence diagrams in Appendix A show the interaction between objects of the EC process and the events that trigger the state change. Chapter 4 talks about the validation of the information model which argues as to how the objectives of the research were met. Chapter 5 summarizes this study and discusses the future work

CHAPTER

II LITERATURE REVIEW

The research into ECM can be divided into management concepts of engineering changes and existence of some industry specific tools. The literature review will give a brief overview of some suggested frameworks and methodologies for managing engineering changes. The following section cites some EC tools which are industry specific. Suggested methodologies and frameworks are discussed along with their inadequacies to manage engineering changes.

2.1 ENGINEERING CHANGE TOOLS

EC tools are specific to particular industries and products since every product has its own product architecture. One of the major problems frequently associated with EC, is to ensure that only current documentation is available to manufacturing areas. Lack of adequate control over documentation can mean that components and assemblies are manufactured to instructions that have become outdated due to a subsequent EC. It is frequently argued that any appropriate computer-aided design (CAD) tool is capable of decreasing the number of engineering changes by giving the engineer increased opportunity for simulation and iteration prior to the launch of a new product or the modification of an existing one. Hays and Sun (1995) on this basis argue that all CAD packages have an effect of reducing the number of engineering changes but not eliminating them.

Huang and Mak (1997) talk about Computer Aided Engineering Change Control (CAECC) systems that create 'electronic forms' equivalent to the traditional ECRs and ECNs. Users with varying roles can use these facilities to capture, retrieve and process

EC data. Kidd and Thomson (2000) cite in-house computer tools made by companies for their own manufacturing operations. The most appropriate example cited by them is of the British Aerospace (BAE) - Military Aircraft Division (MAD). This computer aid has the functionalities of initiating a design change proposal and assessing the viability of a design change. Maull et al (1992) have suggested an ECM process in order to help companies understand what an EC is, its implications on other systems, its costs and how the process of managing the EC can be improved.

Drawbacks of the process: -

- This process can act only as an overall framework and is more inclined to new product development rather than executing an EC.
- This process cannot guide the evaluation of an EC in terms of cost and lead-time. Functional participants do not include other important participants like quality control, purchasing and finance, which might have a role to play in the execution of an EC.

The information model developed as part of this research addresses the above mentioned drawbacks, since it is an EC process model developed from the very basic PD process. Review of engineering changes, which is a part of this model, also addresses the issue of analyzing the impacts on cost and lead-time.

2.2 Block Freeze Mechanism

Huge (1997) suggests the 'Block Freeze Mechanism' for executing engineering changes which is been practiced by many general-purpose computers manufacturers. This methodology is critiqued in this research because it just provides an overall procedural approach rather than an activity-based approach. It consists of the following phases: -

Phase I (0-3 months): This is the period after the release of the initial design drawings to when the first unit is shipped to the customer. Approximately 70 % of the changes occur during this period, which represents 10% of the product life cycle. The author talks about an approach called the 'Block Freeze' approach i.e. changes will be implemented at certain points in time. All the change requests are collected and categorized over this period of time and the period is called the 'Freeze' period. The categorization will depend on the type of the change request. In this case the author has categorized the changes into mechanical, logic, hardware and documentation. This mechanism implements groups of similar changes at one time rather than executing each change one at a time as they are released.

Phase II: This is the phase from 3 to 18 months after the first customer shipment. The design is basically stabilized by this time and the volume of changes is comparatively lesser than the phase I. A Return on Investment (ROI) analysis is performed on all the change requests at this point of time and all the steps after the ROI analysis are the same as in phase I.

Phase III: This period begins after the design has been frozen (approximately 18-24 months) and extends through the rest of the product life cycle. Example: - a new law requiring a safety device or perhaps prolonged field experience would reveal a cost effective reliability improvement.

Disadvantages of the Block-Freeze Mechanism:-

- Changes are collected over a period of time, which is called the 'Block Freeze Period' which will not help execution of changes as a result of contractual obligations.
- This mechanism does not identify the roles of functional participants.
- Like other mentioned mechanisms it does not take into consideration any change request initiated due to change in customer requirements.
- Changes that can occur at the various stages of the PD process are neglected.

2.3 Focused Manufacturing Knowledge

Baruch et al (1993) advocate 'Focused Manufacturing Knowledge' wherein they give an exploratory analysis of how PD engineers can avoid manufacturing-related engineering changes if they develop 'Focused Manufacturing Knowledge'. A design engineer can achieve this by working in an existing area of manufacturing, most related to that engineer's development task. The authors mention analyzing the impacts but do not substantiate the analysis of the impacts in terms of cost, lead time or quality. They recommend implementing change in the prototype before analyzing the impacts of the change. Again the EC process is initiated without evaluating the change request, which happens to be a fundamental drawback of the whole framework.

2.4 EC from the BPR Perspective

Huang et al (1998) have proposed to apply 'Business Process Re-engineering' (BPR) concept to rationalize the ECM process. They have proposed the incorporation of an ECM procedure as a single step in a BPR framework. The authors recommend this procedure for a company, which does not have an ECM system in place. They further substantiate that this framework can be used also by those companies that already have an existing ECM system in place. This framework, which comes nearest to recommending an approach, mentions about evaluating an EC in terms of its impacts. Although it does not mention about analyzing the impacts in terms of parameters it is highly imperative that the impacts can be measured in terms of lead-time and costs.

Although this perspective does not fulfill an efficient EC criterion, it assumes that all changes can be executed in the same manner irrespective of its type. It mentions the characterization of changes into its types as a step after analyzing the impacts. It mentions analyzing the impacts, but like all the above-mentioned frameworks, it does not mention the metrics by which an EC can be evaluated. It does not mention the functional participants and the roles that might be played by them, and it also applies an analogy of BPR to execution of engineering changes.

2.5 Design Parameter Approach

Rouibah and Caskey (2003) have proposed a design oriented approach to engineering changes called 'Design Parameter' approach. They define 'Design Parameters' as basic engineering attributes for which engineering changes have to be implemented. It can be weight, space (length/distance), force, speed, movements and dimension with magnitude and/or direction. They can also be defined as engineering attributes which will have engineering values or whose values have to be changed because of an ECR. Parameters refer to decisions that need to be taken in order to implement an ECR. Design parameters are linked to each other, as are components/sub components for a particular product. Capturing the relationships between them clearly will capture the relation between those functional entities/disciplines (design, manufacturing, quality, etc) that handle these design parameters. Thus design parameters link processes, people and product items (components/sub components). The capture of the inter-relationships between these design parameters can be used to support an intelligent EC process. Rouibah and Caskey (2003) also mention other interdependencies as follows:-

- Interdependent design parameters.
- Design parameters and component/ subcomponent interdependencies.
- Product component/ subcomponent and manufacturing processes interdependencies (product-process) interdependence.
- Product component/ subcomponent and other component/ subcomponent within the same subsystem interdependence (intra-unit product-component coupling).
- Interdependence between product component/ subcomponent and other component/ subcomponent in different subsystems.

2.6 SUMMARY

By far most of the EC studies suggest methodologies which are more inclined toward the administrative issues for ECM. They suggest the basic elements for an EC procedure. There is a void in the approaches toward EC and that is, 'considering EC process as predominantly a process of correcting mistakes rather than a process which should be more aligned toward PD'. Thus engineering changes can also be seen as a way for incremental PD. There are customized tools developed by manufacturing organizations tailored to industry needs. No work has been done which will capture the

EC process flow and the EC data. This research will focus on developing a generic model for all types of engineering changes.

CHAPTER

III THE ENGINEERING CHANGE INFORMATION MODEL

This chapter concentrates on the logical development of the EC information model. Management of the EC process and EC information should happen in an integrated fashion both within the enterprise and outside the enterprise amongst its allied partners. Various metrics (reviewed in chapter2) are used to measure the efficiency of an EC process, some of which are time and cost. Time can be measured in terms of amount of time for requesting an EC, reviewing an ECR, implementing an ECR, amount of unscheduled time for processing an ECR. Cost can be the net cost for making an EC, administration cost of an EC, cost of rework and scrap for an EC and also un-estimated cost for processing an EC and the final costs for implementing those changes.

The following section will discuss the PD process and the possible types of changes that can occur at any of the stages. In section 3.2 the EC process is discussed in terms of its constituting activities. Use case modeling is then used for the various possible ECRs. After enumerating all the relevant use cases the activity model is developed. IDEF0 models are developed for all the constituting activities and sub-activities. Object modeling starts with the identification of all objects corresponding to every activity in the activity model. The dynamic modeling captures the object life cycle of critical objects from the object model.

3.1 THE PRODUCT DEVELOPMENT PROCESS

Different types of engineering changes identified in Section 1.1.5 can arise at various stages in the product design stage. Ulrich and Eppinger (2000) have clearly defined the PD process. The PD process as shown in Figure 1 starts with the identification of customer needs, which includes gathering raw data from customers, interpreting them in terms of customer needs, organizing the needs into hierarchy of primary, secondary and tertiary needs and then establishing their relative importance. This activity is followed by establishing target specifications for the product and then setting final specifications. ECs due to changes in customer specifications can be identified before the development of these product specifications as shown by Figure 1. The customer needs are then analyzed to develop and select product concepts and then test those product concepts. These product concepts are then translated to engineering and technical requirements for the complete architectural design of the product. ECs can arise at this stage due to faults in translation of the customer requirements to technical requirements.

The next step is the architectural design, which involves determination of whether the product will have a 'Modular Architecture' or 'Integral Architecture', (Ulrich and Eppinger, 2000). This is followed by 'Detailed Design' wherein every component /unit/sub-component/part of the product is defined and designed in its minute details. An ECR can arise from the introduction/replacement/withdrawal of an existing component/unit/sub-component/part due to change in customer specifications or environmental or safety considerations. As shown in the Figure 1, ECs can also occur due to difficulty in fabrication or assembly. Changes can also occur during α- testing (In-House) or β-testing (customer site testing). The most significant part to remember over here is that all these changes will result in changed specifications or data which is looped back to any of the preceding stages right from 'development of specifications' to 'fabrication'.

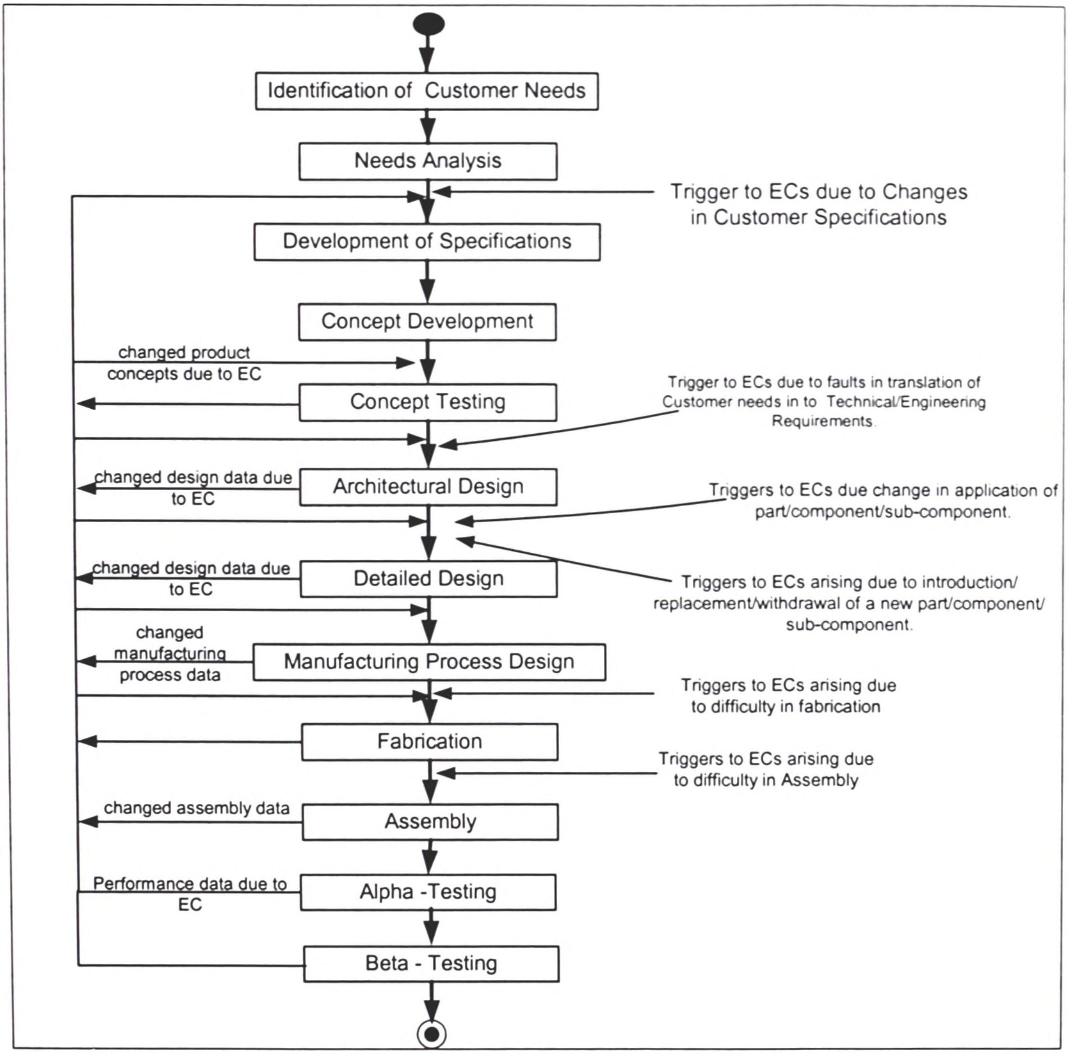


Figure 1: Various ECs relative to the Product Design Stages

3.2 THE ENGINEERING CHANGE PROCESS

The EC process model developed in this research supports extensive communication between many disciplines (functional departments) within the enterprise and also other external entities outside the enterprise. These include change requests coming from the customers' side. Almost all ECM studies agree that communication across functional lines can help avoid many problems (Balcerak & Dale, 1998).

Terwiesch and Loch (1999) suggested extending this inclusive communication beyond functional departments to include suppliers in order to deal with interfacing components affected by change. Literature survey suggests that communication across functional boundaries (such as between Marketing and R&D) apply also to improving the EC process (Souder & Moenart; 1992, 1994). The model developed as part of this research has documented a clear communication procedure in the form of an activity model clearly establishing roles between participants involved in the EC process.

The EC model is a collaborative process model between the process owner and the functional entities/allied enterprises involved. The business process of executing an EC is broken down into its constituting activities as shown in Figure 3. Engineering changes affect downstream activities with regard to product and processes, across departments/disciplines and allied enterprises. This research has developed an EC process model which includes the following steps: - requesting an EC, reviewing an EC, planning an EC and executing an EC. Many authors mention various activities as subsets of an EC process (Huang et al, 2000, 2001; Boznak, 1993; Baruch, 1993). This research captures the ones which are the most critical to the execution of an EC right from the process of requesting the EC till executing it.

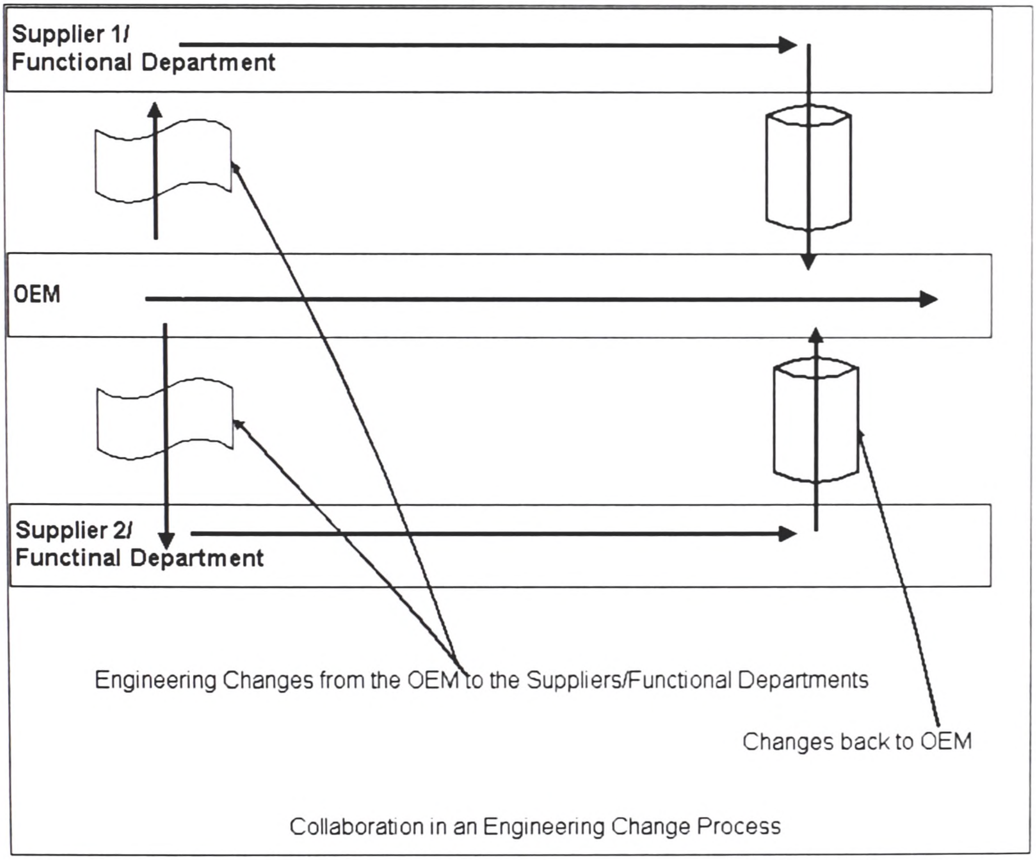


Figure 2: Collaborative EC process

An EC process in general will constitute of the steps, as shown in the Figure 3 which will include the following constituting business activities :-

1. Request an EC.
2. Review an ECR.
3. Plan for EC
4. Execute the EC.
5. Engineering Change Notification.

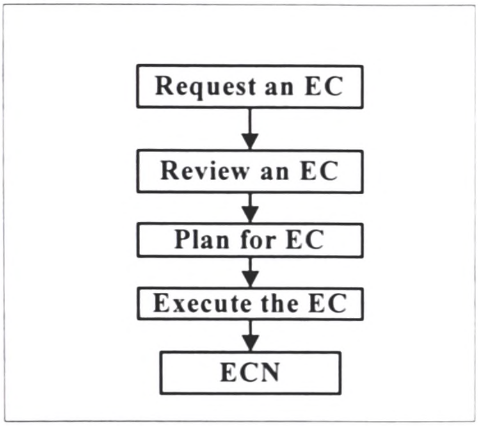


Figure 3: Activities in Engineering Change Management

All the above activities are used to develop the information model which is a generic model to manage engineering changes. Refer to Figure 4 to get an overview of the logical development of the model which starts with the use case modeling and ends with the dynamic modeling. Please refer to the activity diagram –Appendix B for executing an EC. The process starts with an ECR put forth by a customer or by an internal functionality (functional department). The ECR is routed to the EC board/committee. The next activity of. 'Review an ECR' is broken down in to technical review and economic review. Any EC related to a product design trickles down to the manufacturing processes related to its manufacture, the materials used for the manufacture and also the fabrication, assembly and also the testing of the product.

The following reviews are conducted in order to determine whether the ECR is feasible or not. The 'Design Review' determines the components/sub-components/parts that are affected by the EC. The 'Manufacturing process review' determines the effect of the EC on the manufacturing process. The change will also affect quality, which then becomes a responsibility of the quality control/assurance department for safeguarding -

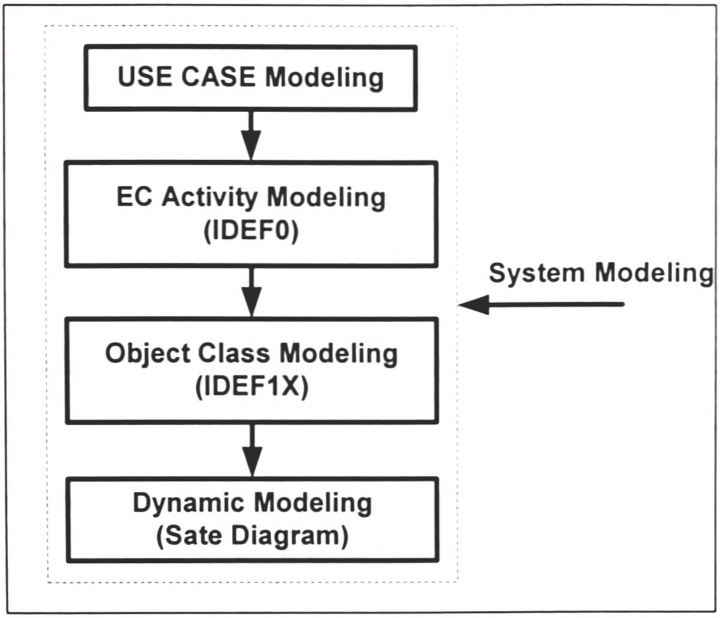


Figure 4: Overview of the Development of the Information Model

conformance to specifications as a result of the EC. The 'Quality Review' determines how the EC will impact the quality of the product / component /sub-component which is carried out by 'Quality Control'. Engineering changes and time delays are also intricately related as pointed out by Hegde et al. (1992). Engineering changes also affect the completion time of jobs thereby affecting the scheduling of the engineering changes. Thus a 'Scheduling Review' has to be conducted in order to determine the time delays that will arise due to implementation of engineering changes. Bottleneck operations and unscheduled downtime are also the factors that should be considered in the 'Scheduling Review'. After making an ECR, it is reviewed by the EC committee and the respective functional department. All the above mentioned technical reviews will serve as a right platform for the EC board to make a detailed cost-analysis which is termed as 'Cost-Review'. The 'Cost Review' is carried out to determine the economic feasibility of executing the EC. The outcome of the EC review will be an approved ECR, a rejected ECR or an EC quote/estimate given to the customer. Once the approval of the customer is obtained the EC board/committee will create the ECO. The ECO will then be routed to the responsible functional department(s) for implementing it. The activity of implementing the ECO can be broken down into 'incorporating the EC in fabrication', 'incorporating the EC in assembly' and 'incorporating the EC in testing'. Once the ECO is implemented an ECN is created by the department implementing the change and routed to the EC board/committee and other departments affected by the change.

The next step is the post-implementation assessment which determines whether the implemented change has met its desired goals and objectives (qualitative assessment) and quantitative assessment. The activity of quantitative assessment involves assessing the performance data derived after implementing the EC and comparing the performance data with the technical data existing before executing the EC.

3.3 Use Case Modeling

Use cases are written for the activities that constitute the EC process which starts from making an ECR, reviewing the ECR, planning the EC (creating the ECO) and then creating the ECN. Refer to Table 1 below for the use case of 'request an EC'. According to Jacobson et al (1992, 1994, 1999), a use case describes all the details of a business process. The business process is thus viewed as a 'behaviorally related sequence of interactions performed by an actor in a dialogue with the system to provide some measurable value to the actor' (Jacobson et al. 1992, 1994). Use cases represent ways of developing an information model in terms of set of scenarios, while actors represent roles that have specific sets of responsibilities relating to use cases.

Table 1: Use case for 'Request an EC'

Use Case Name	**Request an EC**	
Actor(s)	Customer(s), Functional department and EC board/committee.	
Trigger	ECR initiated by any of the actors mentioned above.	
Typical Course of Events	Actor(s) 1. This use case is initiated when actor(s) make(s) a request for an EC with the engineering/technical requirements, expected result from the EC and order specifications. 4. This use case concludes when the EC board/committee (leader) receives an ECR.	System Response 2. The relevant EC information (type, description, urgency etc.) is stored in the system (database). 3. The system generates an ECR for the corresponding request made by the actors.
Alternate Course of Events	None at this time.	
Precondition	ECRs can be submitted by the actor(s) only.	
Post Condition	An ECR is submitted by the customer/functional Department.	

Table 2: Use Case for 'Review the ECR'

USE CASE NAME	Review the EC Request	
Actor(s)	EC board/committee & Functional departments.	
Pre Condition	ECR submitted by the customer/functional department.	
Typical Course of Events	Actor(s)	System Response
	1. The EC board receives the ECR with the EC item.	
	2. The EC board conducts a design change review which will also involves engineering and design.	
	3. The design and engineering department submit the results of the design review to the system (database).	4. The system records results of the design review.
	5. The EC board and the production department conduct the manufacturing process review to determine the changes in the manufacturing processes due to the EC.	
	6. The EC board and the production department submit the results of the manufacturing process review to the system.	7. The system records results of the manufacturing processes review.
	8. The EC board and inventory control conduct the materials review to determine the changes in raw materials/BOM.	
	9. The EC board and the inventory control submit the results of the materials review to the system.	10. The system records the results of the materials review.
	11. The EC board and quality control conduct quality review to determine the impacts/changes on quality due to the EC.	
	12. The EC board and quality control submit the results of the quality review to the system.	

Table2: Use Case for 'Review the ECR (contd)

USE CASE NAME	**Review the EC Request**	
Actor(s)	EC board and the functional department.	
Pre Condition	ECR submitted by the customer/functional department.	
Typical Course of Events	Actor(s)	System Response
		13. The system records the results of the quality review.
	14. The EC board and manufacturing conduct the scheduling review to determine the possible changes in schedule due the EC.	.
	15. The EC board and manufacturing submit the results of the scheduling review to the system.	16. The system records the results of the scheduling review.
	17. The EC board and finance/purchasing conduct the cost review to determine the possible economical impacts of the EC.	
	18. The EC board and finance/purchasing submit the results of the cost review to the system.	19. The system records the results of the cost review.
Alternate Course of Events	The EC board sends the ECR with an EC quote/estimate to the customer.	
Successful End Condition	Most of the reviewers on the EC board support the change.	
Failed End Condition	Most of the reviewers on the EC board are against the change.	

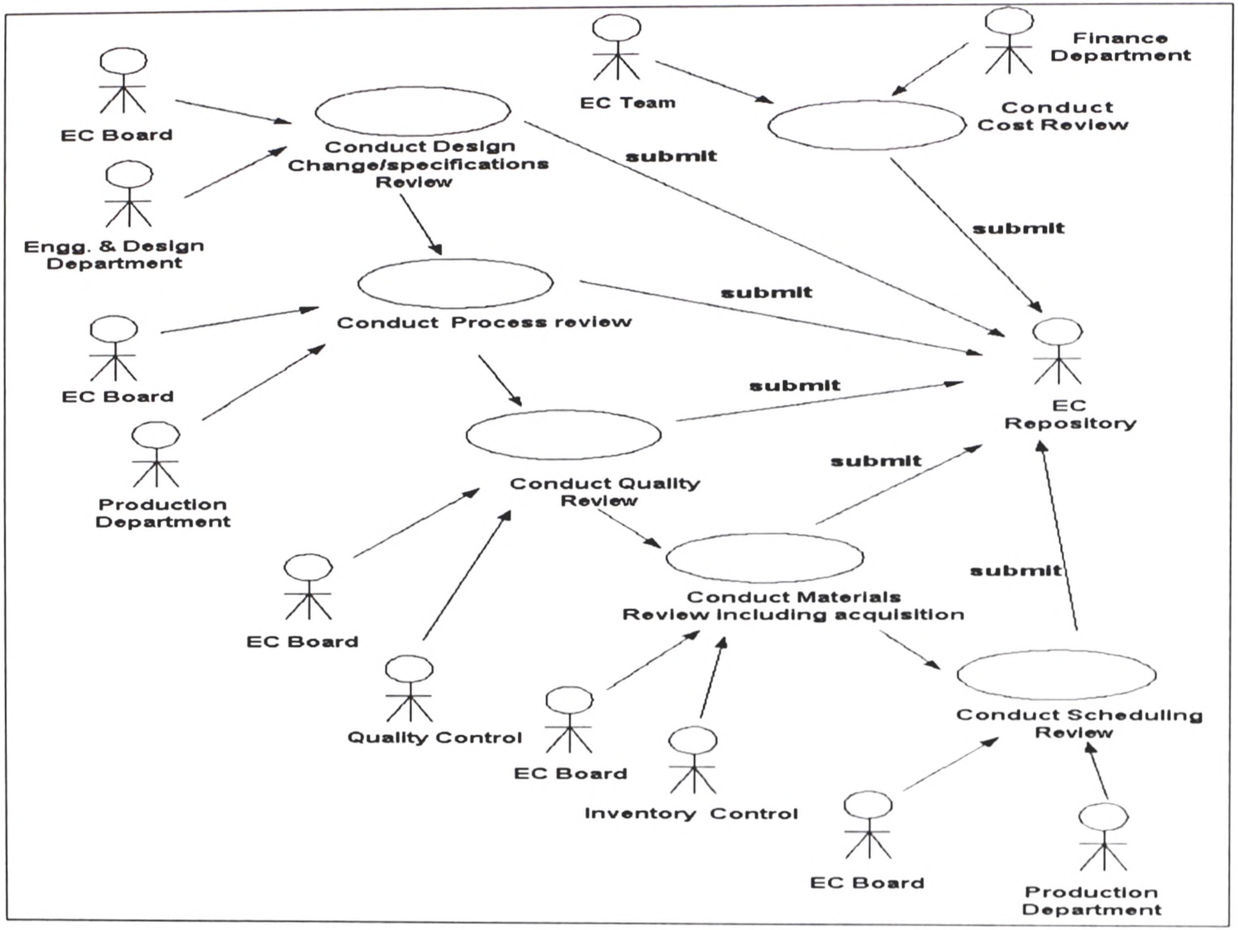


Figure 5: Use Case diagram of 'Review an EC'

Table 3: Use Case for ‘Plan for EC’

Use Case Name	Plan for EC	
Actor(s)	EC board, Functional department	
Goal on Context	After the approval of the ECR the ECO will be created.	
Pre Condition	ECR is approved by the EC board	
Typical Course of Events	Actor(s)	System Response
		1. After the ECR is unanimously approved by the EC board the EC board leader creates an ECO with customer specifications and EC related data.
	2. The EC board leader fills out the ECO and submits it to the system.	
		3. The system records the ECO in the system database.
Alternate Course of Events	None at this time	
Successful End Condition	An ECO is created by the EC board leader.	
Failed End Condition	None at this time.	

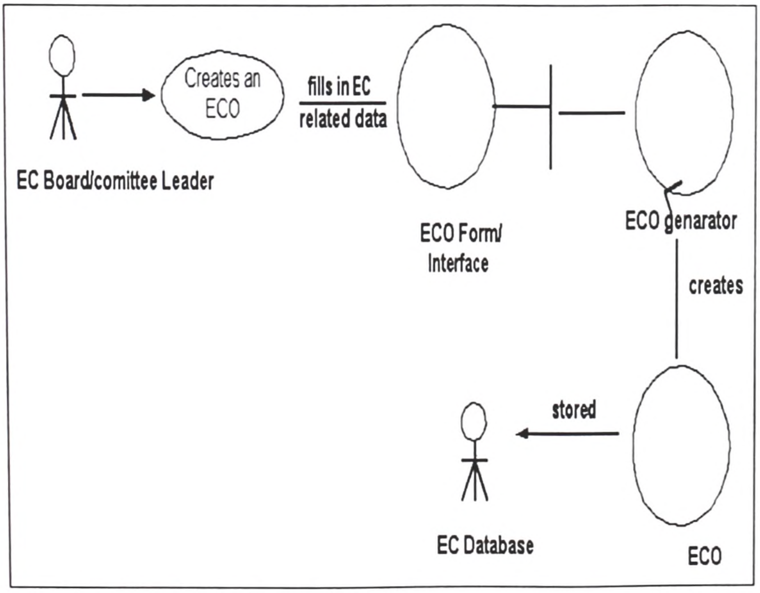


Figure 6: Use Case diagram for 'Create an ECO'

Table 4: Use Case for 'Execute the ECO'

CASE NAME	Execute the EC	
Actor(s)	EC board and Functional departments.	
Trigger	ECO created by the EC board leader.	
Typical Course of Events	Actor(s) 1. This use case starts when the EC board leader routes the ECO to the concerned department. This will be functionalized ECO. 3. The concerned department(s) implement(s) the change according to the ECO. 4. While implementing the change the implementing department(s) also prepares the EC progress report and submits it to the system. 6. The implementing department generates the ECN once the EC is completely implemented. 7. The implementing department routes the ECN to the EC team and to other departments effected by the change and submits the ECN to the system.	System Response 2. The system records the functionalized ECO in the system database. 5. The system records the EC progress report in the EC database to be archived later in the future. 8. The use case ends when system records the ECN details.
Alternate Course of Events	None at this time	
Successful End Condition	ECN creation.	
Failed End Condition	If the EC is not completely implemented then the status will be mentioned as incomplete/in-progress on the EC progress report(s).	

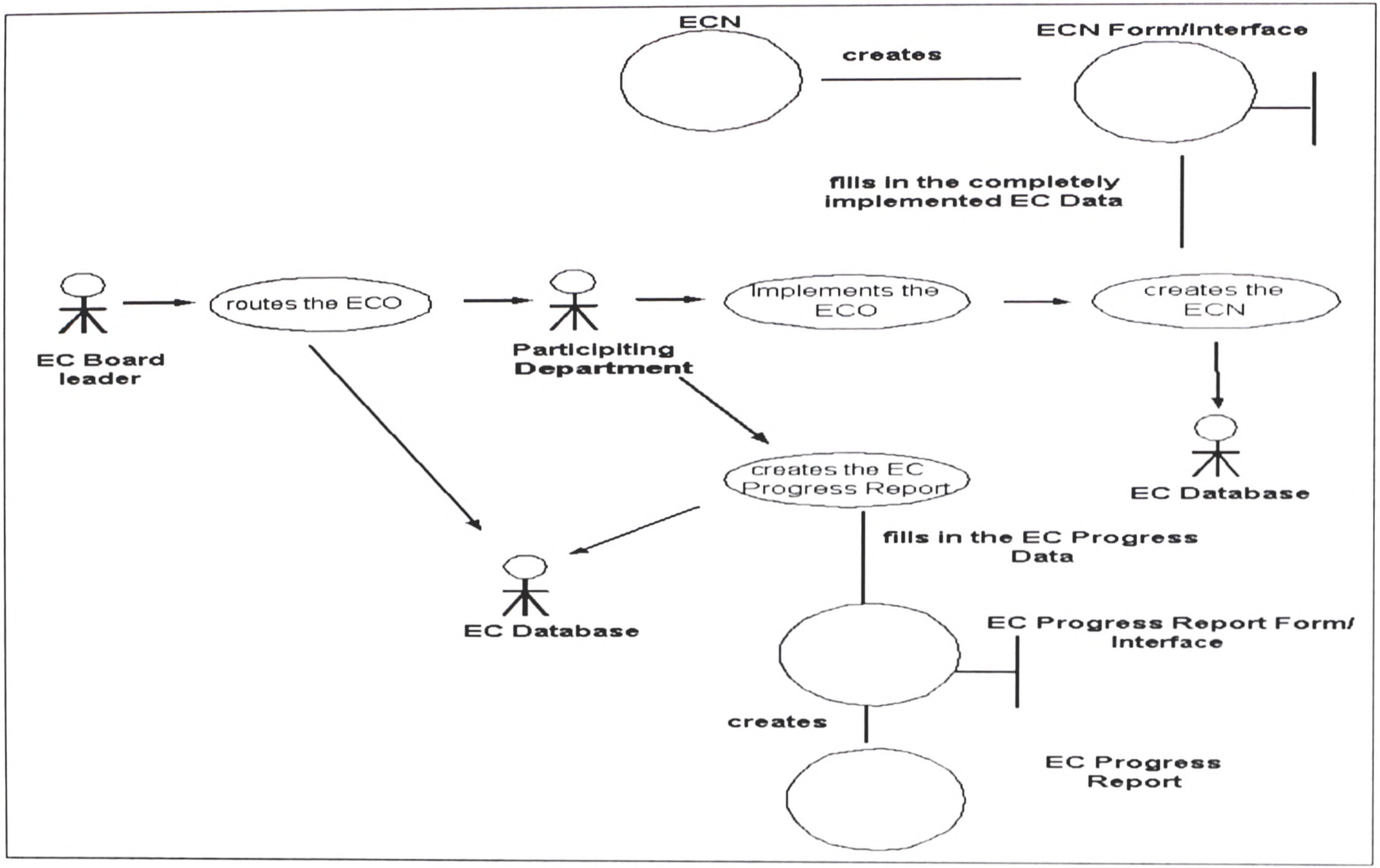


Figure 7: Use Case diagram of 'Execute the EC'

Table 5: Use Case of 'Post Implementation Assessment'/ECN'

CASE NAME	Post Implementation Assessment/ECN	
Actor(s)	EC board/committee and functional department	
Goal on Context	To asses the results of the implemented EC both quantitatively (scrap, rework etc.) and qualitatively (achievement of goals/objectives).	
Trigger	ECN received by the EC board/committee leader.	
Pre Condition	The EC has to be executed.	
Typical Course of Events	Actor(s)	System Response
	1. This use case begins when the EC board/committee leader and the concerned functional departments receive the ECN. 2. Upon receipt of the ECN the EC team conducts the qualitative assessment of the EC. 3. The results of the qualitative assessment are submitted to the system.	
		4. The system records the results of the qualitative assessment of the EC.
	5. The EC board/committee conducts the quantitative assessment of the EC and measures it against the performance data. 6. The EC board/committee submits the performance data to the system.	
		7. The system records the performance data. 8. The use case ends when the system records all the relevant details of the EC and generates the EC result report.
Alternate Course of Events	If the post implementation assessment is negative then the feedback along with the necessary alterations to the engineering change are sent back to the concerned functionalities responsible for executing the change.	
Successful End Condition	The outcome of this step is a set of performance data that gives valuable insights to the changes due to the executed ECs and the EC result report	
Failed End Condition	The new performance data indicates failure or incapability to achieve the required results in terms of technical requirements or customer specifications.	

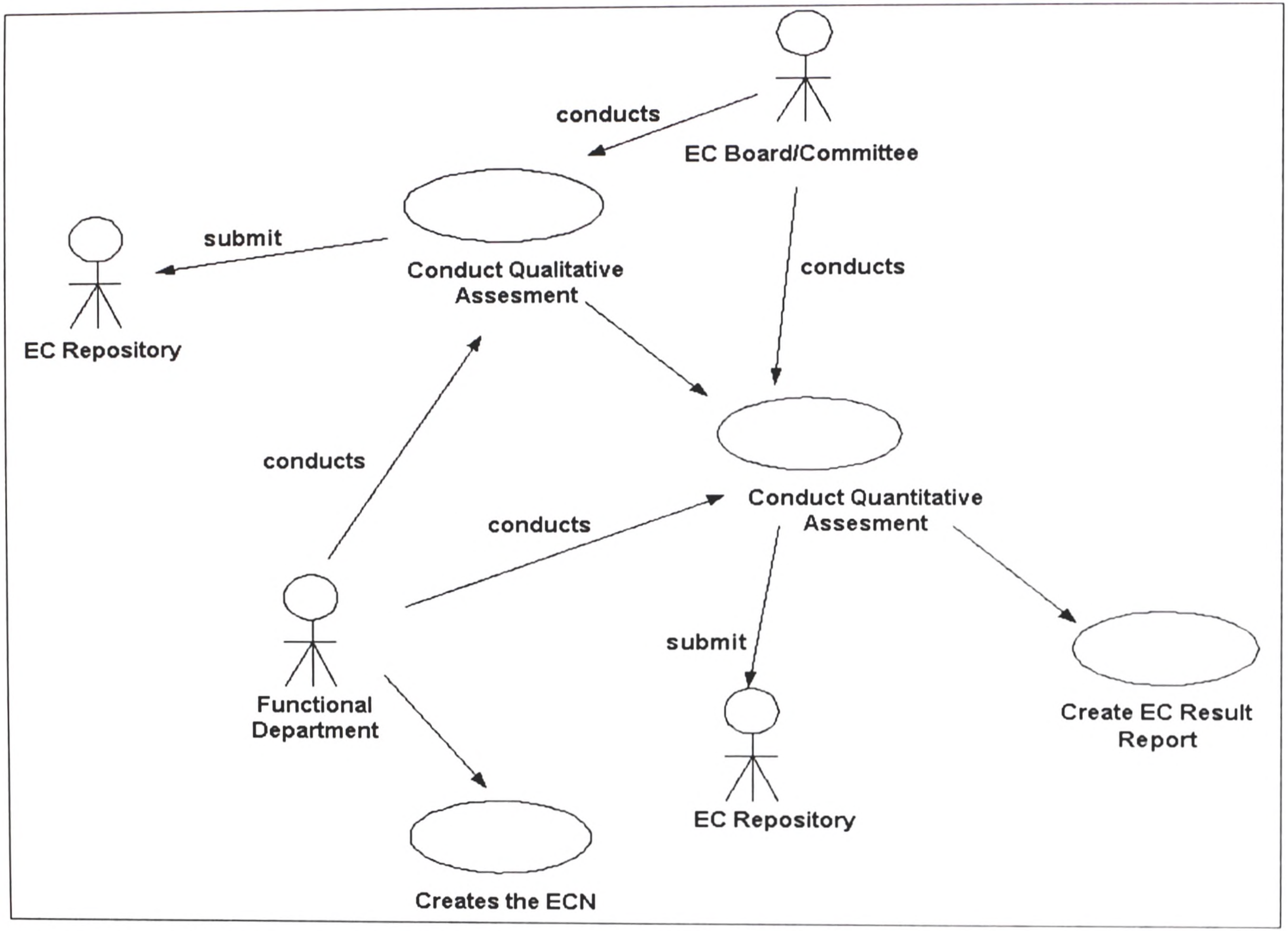


Figure 8: Use Case diagram of 'Post-Implementation Assessment/ECN'

3.4 ACTIVITY MODELING

The first step was to clearly depict the different types of change requests in terms of the use cases mentioned above from Table 1 through Table 5. These are the activities that have to be carried out while executing an EC. The activities depicted in the use cases are broken down in to its logical sub-activities so as to develop a comprehensive activity model for the execution of engineering changes. The IDEF0 diagram for managing engineering changes is shown in Figure 9.

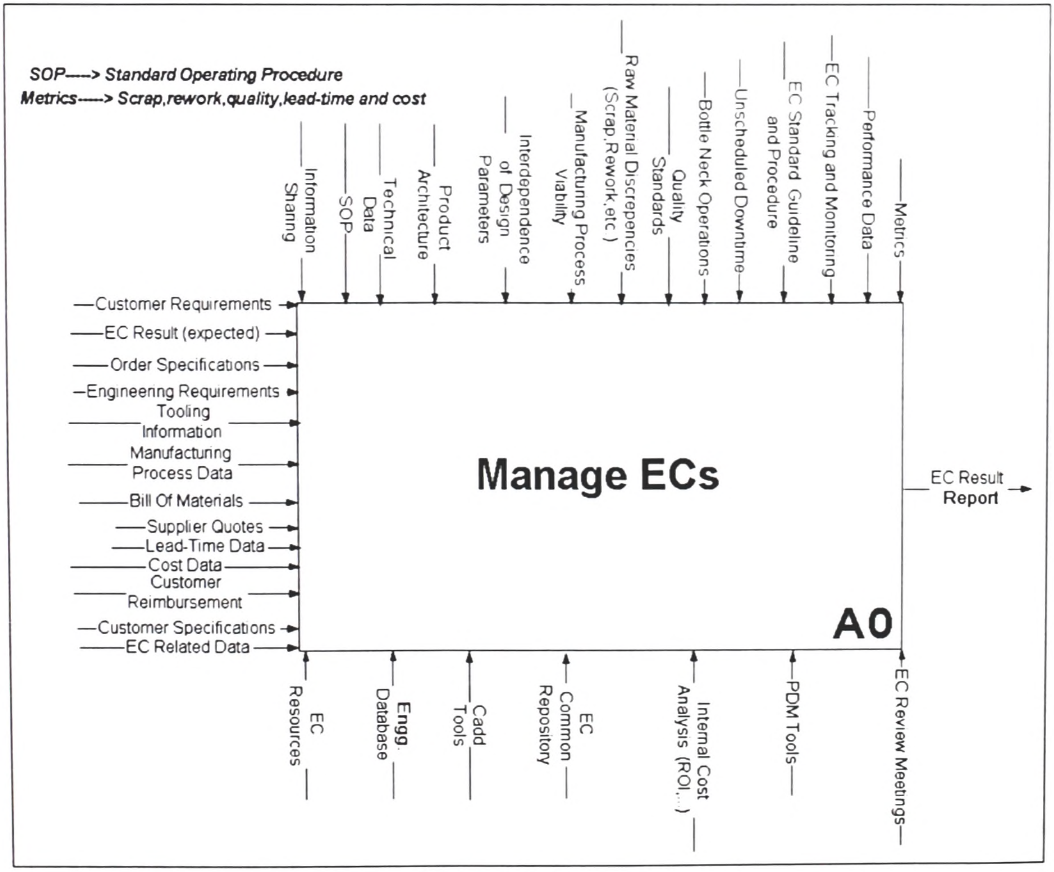


Figure 9: IDEF0 diagram of 'Managing an Engineering Change'

The model developed for the execution of an EC provides a complete overview of an EC process model that can be developed using the activities represented by the node tree in Figure 10 . A21, A22, A23, A24, A25 & A26 (child nodes of A2) are the child activities of the parent activity A2 (parent node A2). A421, A422 and A423 are the child nodes of the sub-activity A42. A51 and A52 are child nodes of parent node A5.

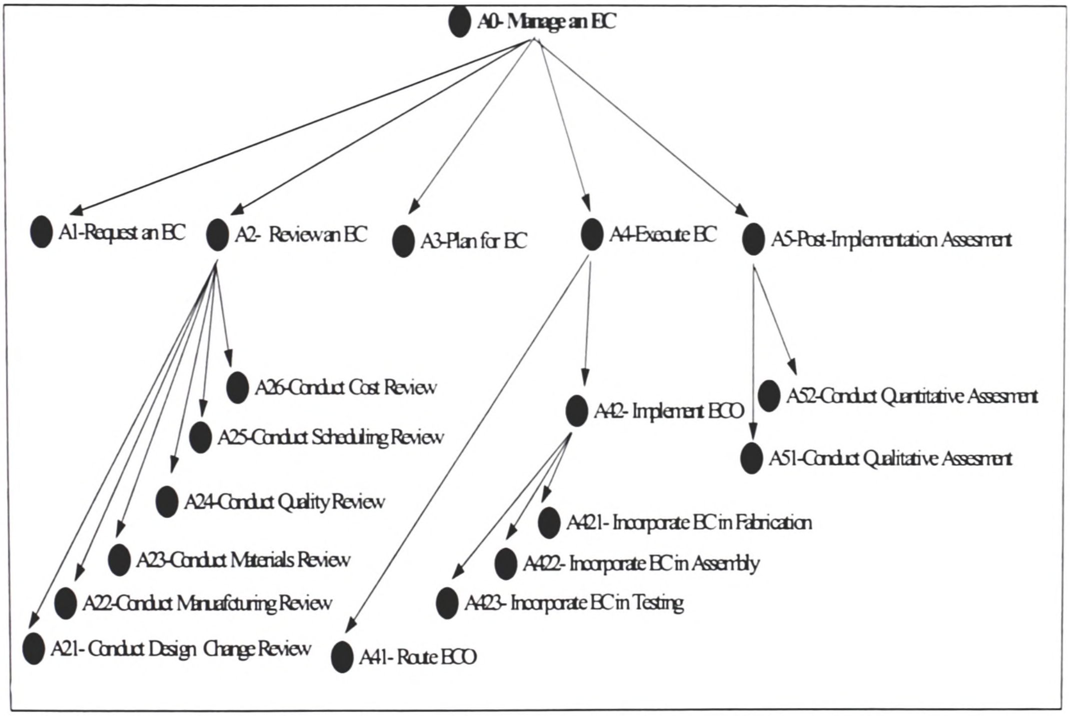


Figure 10: Hierarchical diagram of activities to mange ECs.

The EC activities mentioned have been analyzed for the inputs, outputs, resources and mechanisms that are required to execute them and then IDEF0 diagrams have been drawn for every activity. The first and most obvious step after identifying an EC is to convert it in to an ECR. Every ECR is characterized by the following inputs: - customers' requirements which are the trigger for initiating an EC, the intended EC result, the engineering/technical requirements of the EC and order specifications as mentioned by the customer. The mechanisms, which have a direct control over all these EC activities, are CAD tools (CAD/CAM/CAPP/CAE software), engineering database, EC common repository and the engineering resources/equipments that play a vital role in the execution of each and every activity. Whenever there is an ECR/RFQ (Request for Quotation) submitted by the customer for an EC three important questions should be answered by the EC Board/committee:

Q1: Can the EC be executed?

Q2: What will be the technical implications- manufacturing processes affected, materials (BOM) affected due to the change, quality impacts, scheduling impacts?

Q3: What will be the cost incurred?

The output of the EC review will be either in the form of rejected ECRs, EC quotes/estimates to customers who will bear the cost of the EC or the approved ECRs themselves which are ready to be implemented. Those ECRs that have to be modified are sent back for modifications to the requesting party. The activity of executing the EC will have an output of EC progress report submitted to the EC board/committee. In case of completely implemented engineering changes, an ECN is issued to inform all the concerned entities about the implementation of the change. The complete Activity model is shown in Figure 11.

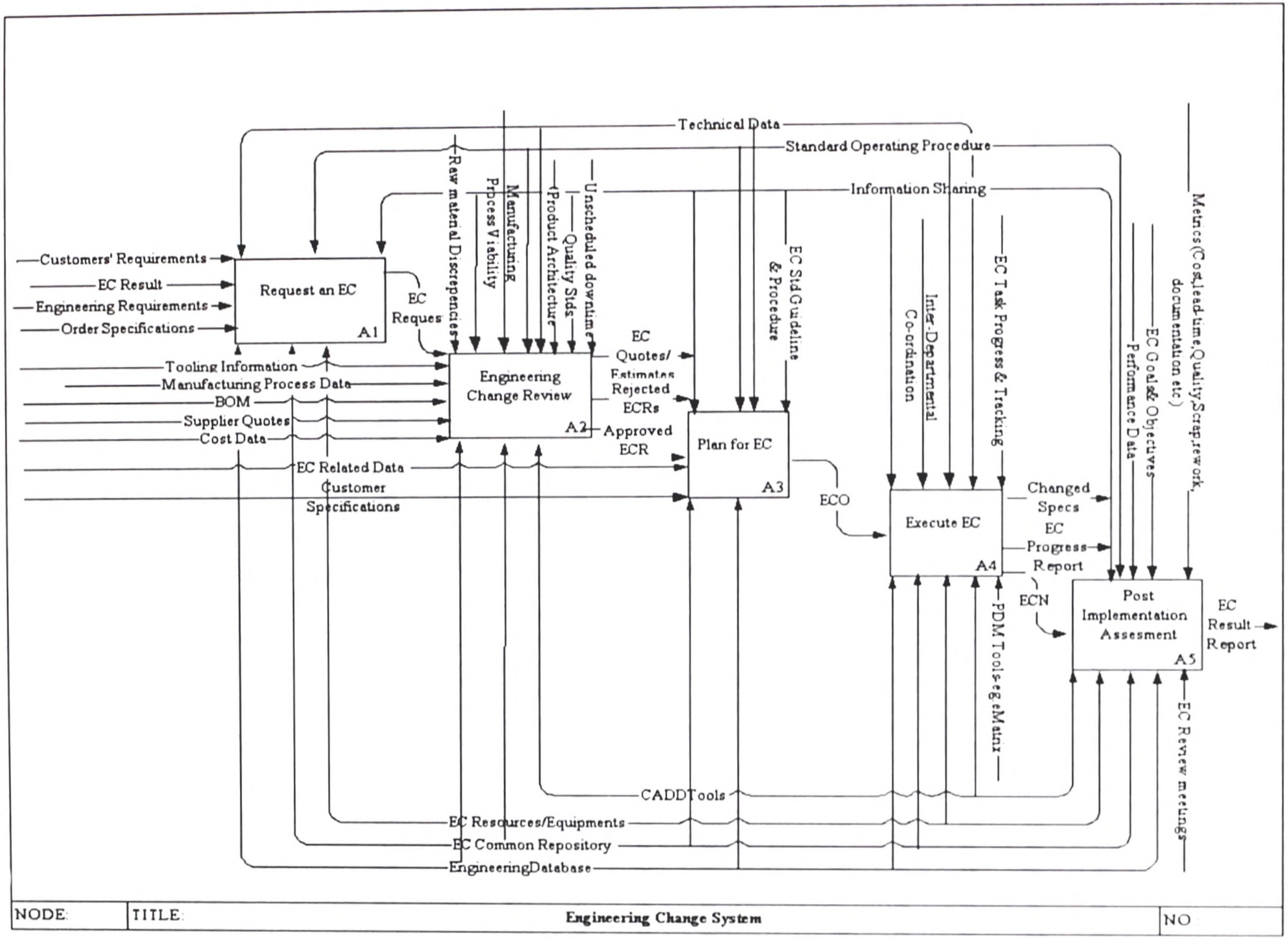


Figure 11: The IDEF0 Activity Model for 'Managing Engineering Changes'

Every activity in Figure 11 shown above will be depicted in to its sub activities starting with activity A2. Refer Figure 12 to see the logical break down of the activity A2. This activity starts with the design review. The design review analyzes the product design for any design change, followed by the manufacturing process review that will take in to consideration the manufacturing processes that will be affected. Apart from the above mentioned reviews, other factors that would be affected by change will be the materials used for the manufacturing. The BOM and supplier quotes will act as inputs for the materials review to be conducted as part of the EC review. The result of a materials review will be a modified BOM. The quality control department will also take in to account the impacts on the quality of the product due to the EC.

One more aspect to be considered will be the effect on the scheduling (Hegde, 1992), since it is really important to determine whether the EC can be implemented on time. Last but not the least, the conclusions from the above mentioned reviews will provide as the right base to conduct a cost analysis/cost review to come up with an estimate or quote to be given to the customer as costs to be incurred to implement the EC. The decomposed IDEF0 model for the activity of 'review an engineering change' into its sub-activities is shown in Figure 12.

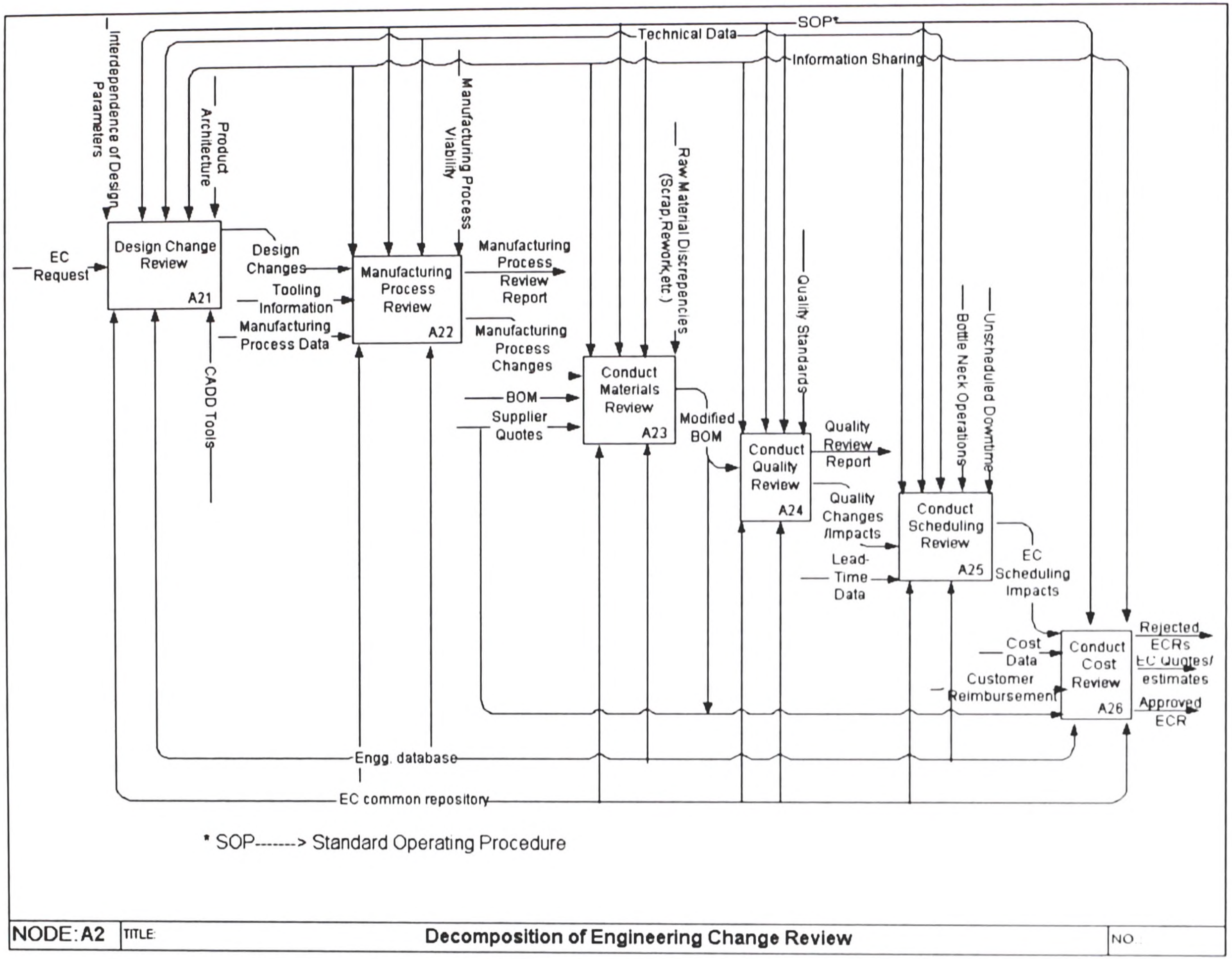


Figure 12: The decomposed IDEF0 Model of 'Review an Engineering Change'

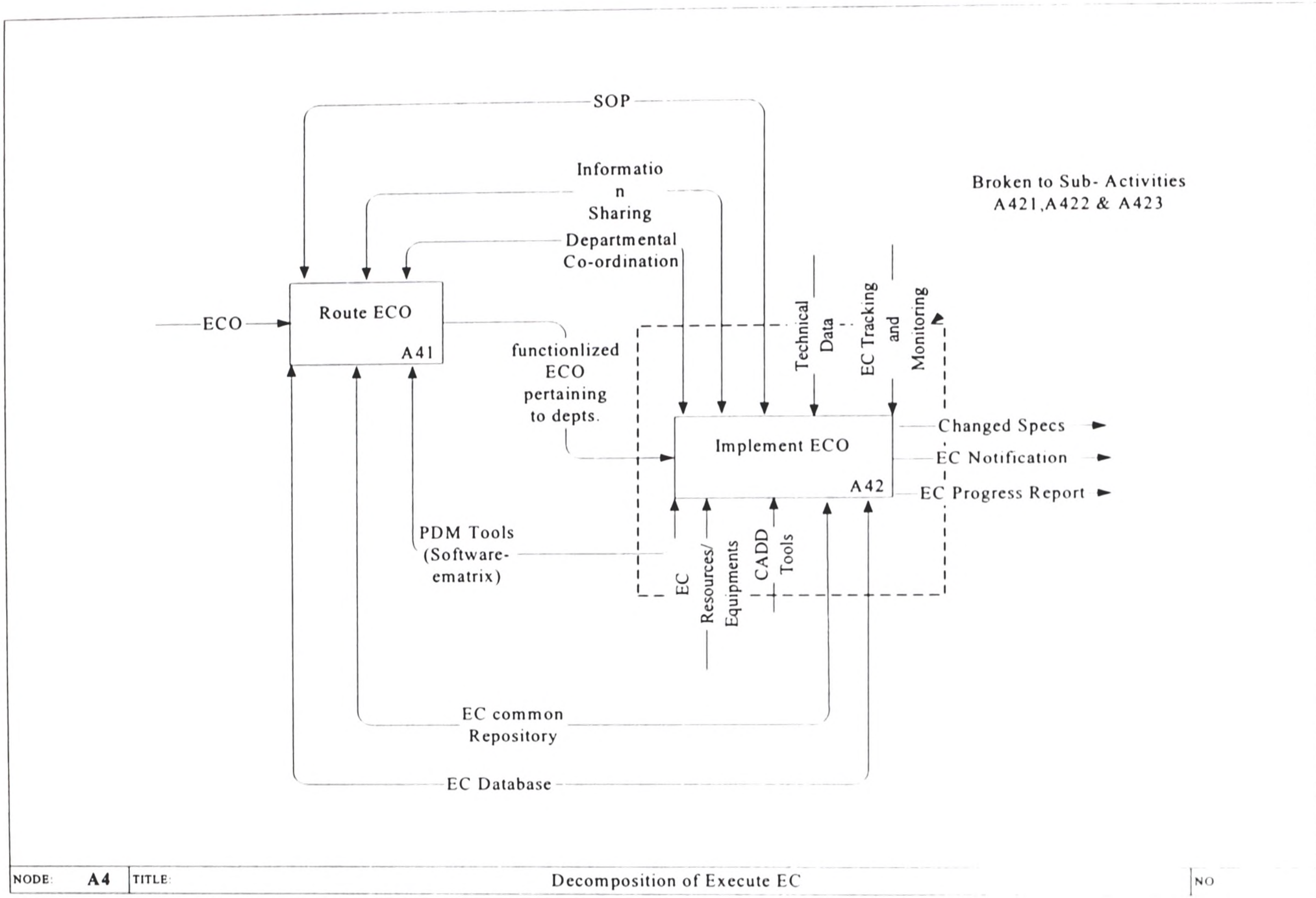


Figure 13: The IDEF0 Model of 'Execute an EC'

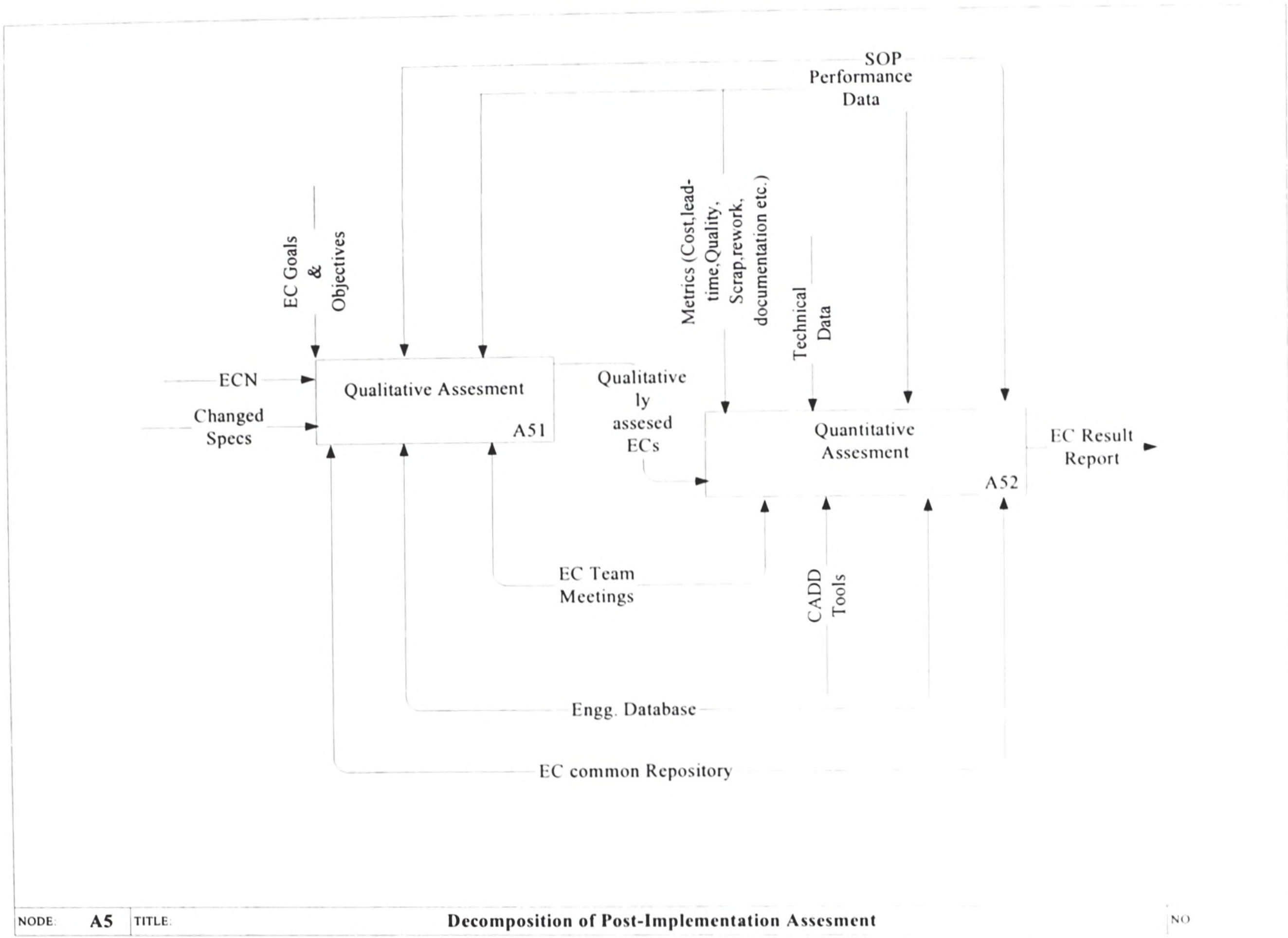


Figure 14: The IDEF0 Functional Model of 'Post-Implementation Assessment'

Please refer Figure 15. The sub-activity A42 (implement the ECO) can be broken down into its logical sub-activities – i.e. 'implement EC in fabrication', 'implement EC in assembly' and 'implement EC in testing'. The IDEF0 diagram for the above mentioned sub-activity is as shown in Figure 15. An EC can affect the fabrication of a part/sub-component/component. The function of making a product/part/component from its constituting raw-materials is called 'fabrication'. The inputs to this activity are the raw-materials that go into its fabrication. Material properties act as a control over this activity. An EC can thus affect the fabrication of the component and the EC has to be incorporated in the process of fabrication. Fabrication can also give rise to modifications that need to be made to the customer specifications. The output of this sub-activity will be a fabricated part/component/sub-component which goes into assembly. After assembly the part/component/sub-component has to be tested in accordance with quality standards and customer specifications. The most important fact to remember here is that fabrication, assembly and testing can all result in modifications that need to be made to the customer specifications depending on the type of EC as shown in Figure 15.

The decomposed IDEF0 diagram of every activity right from A1 to A5 is used to construct the activity model. The model incorporates in detail the constraints, the inputs and the outputs of every sub-activity. The logical decomposition of every activity gives rise to the final activity model which then will be further used to develop the object model for executing an EC.

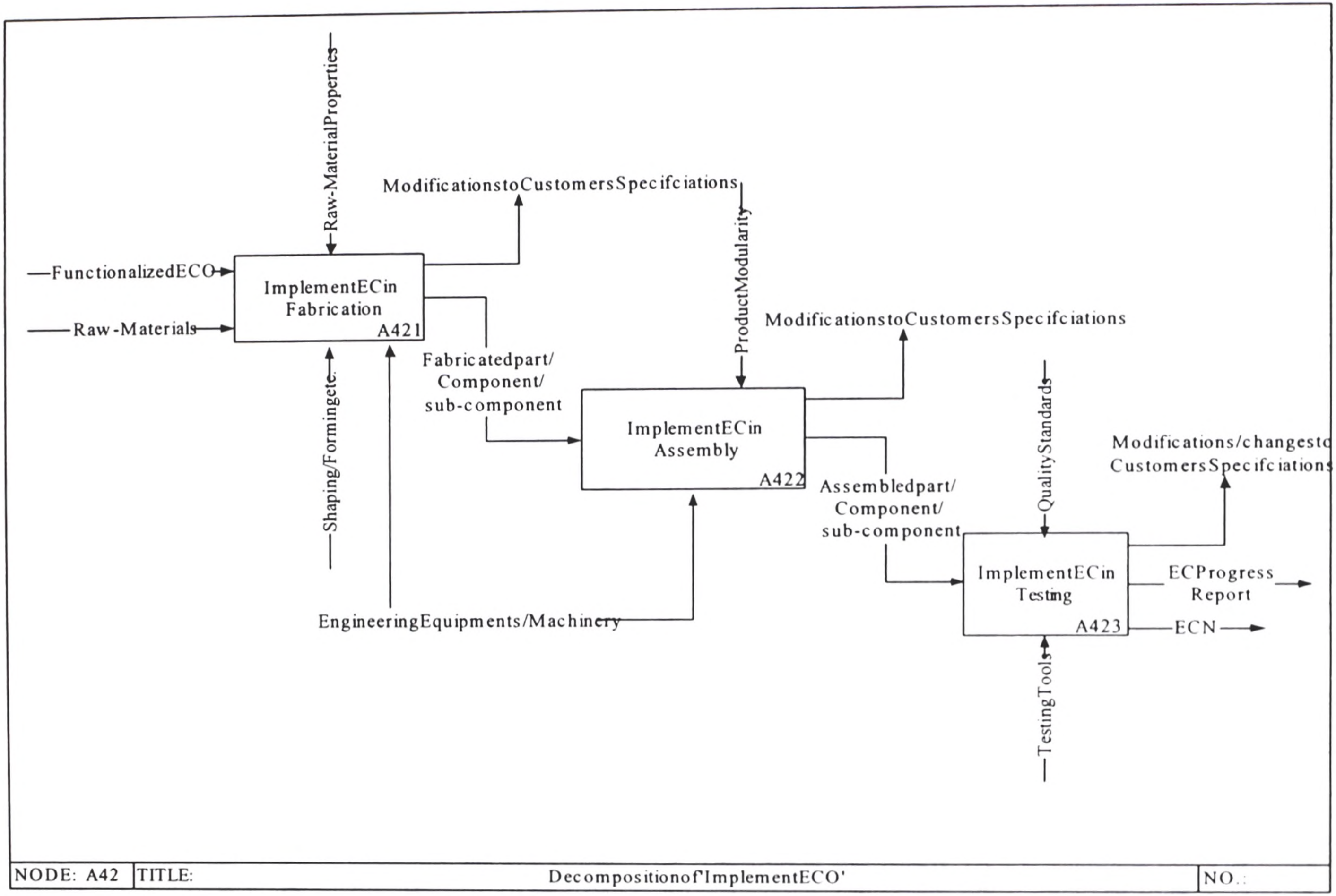


Figure 15: The IDEF0 Functional Model for decomposition of 'Implement ECO'

3.5 Object Modeling

Object modeling has two purposes of capturing all objects in the EC process from the activity model and defining these objects in terms of their attributes. Object modeling also helps to create a seamless transition from a business process to an ECM information system. Objects were extracted from every activity of the activity model right from 'request an EC' to 'execute an EC.'

Object class diagrams were drawn for objects derived from every activity and their cardinalities were shown in the object class diagrams. Every object was defined in terms of its attributes. Table 6 shows a list of all objects that have been identified from the activity model. The first column of shows the name of the data entity, the second column shows the object type and the third column shows the activity from which the object is extracted. From the comprehensive list of objects as shown in Table 6 the objects will be segregated depending on which activity they belong to and then these objects were defined in terms of their attributes. For instance the analysis of the first activity 'request and EC' resulted in identification of the following objects: ECR, customer, order specifications, functional department and EC board. Refer to Table 8 for the attribute table of the object ECR. The primary key of the object ECR is an ECR number which is a unique identification number to identify a particular ECR. The other important attributes are the change description, request type, EC title and the status of the ECR.

Table 6: Complete object list from Activity Model

Entity name from activity model	Object type	Activity from which object originates
ECR	Entity	'request an engineering change'
Customer	Entity	'request an engineering change'
Specifications	Entity	'request an engineering change'
EC result	Entity	'request an engineering change'
EC Quote	Entity	'review an engineering change
EC review	Entity	'review an engineering change'
EC review report	Entity	'review an engineering change'
EC board	Entity	'review an engineering change' 'plan for engineering change'
EC goal	Entity	'Post implementation assessment'
Changed specification	Entity	'execute an engineering change'
Engineering process	Entity	'review an engineering change'
Product item	Entity	'request an engineering change' 'execute an engineering change'
Supplier quote	Entity	'review an engineering change request'
EC result report	Entity	'post implementation assessment'
EC board	Entity	'review an engineering change'
EC item	Entity	'execute an engineering change'
ECN	Entity	'execute an engineering change'
EC progress report	Entity	'execute an engineering change'
ECO	Entity	'plan for engineering change'
EC cost	Entity	'review an engineering change
BOM	Entity	'review an engineering change'
EC board member	Entity	'review an engineering change'
Functional Department	Entity	'review an engineering change' 'execute an engineering change'
EC review report	Entity	'review an engineering change'
EC project	Entity	'plan for engineering change'

Table 7: List of objects for the activity 'Request an EC'

Entity name	Object Type
ECR	Entity
EC Board/committee	Entity
EC Committee leader	Entity
Functional Departments	Entity
Customer(s)	Entity

Table 8: Attribute table of the object 'ECR'

Object Name	**Engineering Change Request (ECR)**
Definition	A request submitted in order to bring into effect an engineering change to a particular product, part, component, sub-component, process, supplies or even a process.
Attribute Name	Definition
ECR #	A unique identification number for identifying an EC. This will be used as the primary key for the object ECR
EC Title	The title describing the EC in short/ name of the ECR.
Request Type	Mentions the type of the EC-customer specified, design change process change, materials change etc.
Department ID	The department ID of the functional department initiating the ECR. This can also act as the Alternate Key (AK) for the object.
Change Description	Every EC can be described in terms of its technical requirements, customer order specifications and expected EC result.
Status	Every ECR is reviewed for its feasibility and the end result of this is an ECR that can have a status of [approved/rejected/modified].
Request Date	Date the request was submitted.
Approval Date	Date indicating the approval of the request.

Table 9: Sample of an 'ECR'

GYC Engineering Change Request (ECR)	
ECR #:	002
Submitted by	Delta Industries (Customer)
Title	MPS Cost Reduction
Request date	03/04/2004
Status	Approved
Approval Date	03/29/2004
Change Description	1. Reduce efficiency requirement in section 6.2 from 65% to 60%. 2. Remove the requirements that the 5VSB output stay on during a power supply shut down due to an over temperature condition.
Order ID	The order number corresponding to the engineering change.
Item ID	The ID for the item (process, product, component, etc.)which undergoes the EC
Cost	The estimated cost for the engineering change.
Approved by	The approval of the EC board leader for the engineering change.

Table 10: Attribute table of the object 'EC board/committee'

Object Name	Engineering Change Board/Committee
Definition	The EC change committee that looks over the management of ECs. Functionalities- reviewing, approving, tracking and implementing ECs.
Attribute Name	**Definition**
EC board/committee_ID(PK)	A unique identification number for identifying EC committee. This will be used as the primary key for the object ECR
EC board leader	The leader of the EC board. Usually lead by the head of a functional department.

Table 11: Attribute table of the object 'EC board/committee leader'

Object Name	Engineering Change Board/Committee Leader
Definition	The leader of the EC committee.
Attribute Name	**Definition**
SSN(PK)	A unique identification number for identifying EC committee leader. This will be used as the primary key for the object EC board leader.
Department ID	The department ID of the functional department from which the EC board leader is.
Employee ID	The employee ID of the EC board Leader.
Designation	The designation of the EC board leader in the functional department.

Table 12: Attribute table of the object 'Functional Department'

Object Name	Functional Department
Definition	The functional departments which can submit an ECR. Example- design, manufacturing, inventory control, quality control, production, marketing etc.
Attribute Name	**Definition**
Department_ID (PK)	The department ID of the functional department initiating the ECR. This is the primary key for the object- functional department.
Department Name	Name of the functional department.
Department Manager	Manager of the functional department.
Department Strength	The numerical strength of the department
Department Function	Primary function of the department-design, manufacture, production, inventory control, marketing etc.

Table 13: Attribute Table of the object 'Functional Department'

Object Name	Customer
Definition	The customer or the client of putting in the ECR.
Attribute Name	**Definition**
Customer_ID (PK)	The unique identification number assigned to the customer. This will be the primary key of the object-customer.
EC Item	The item for which the customer is requesting a change-process,part,component,subcomponent,supplies,documentation etc.
Customer Specifications	The technical specifications as needed by the customer.

Table 14: List of Objects of 'Review an EC' Use Case

Entity Name	Object Type
EC Review	Entity
EC Quote	Entity
EC board Member(s)	Entity
EC Item	Entity
EC Review Report	Entity

Table 15: Attribute table of the object 'EC Review'

Object Name	EC Review
Definition	The review of an ECR done before approving or rejecting it.
Attribute Name	**Definition**
EC Review_ID (PK)	The unique identification number assigned to any EC review. This will be the primary key of the object- EC review.
Review Date	The date the review was conducted by the EC board/committee.
Review Type	The type of review conducted-design review, cost review, scheduling review, manufacturing process review, materials review, quality review.

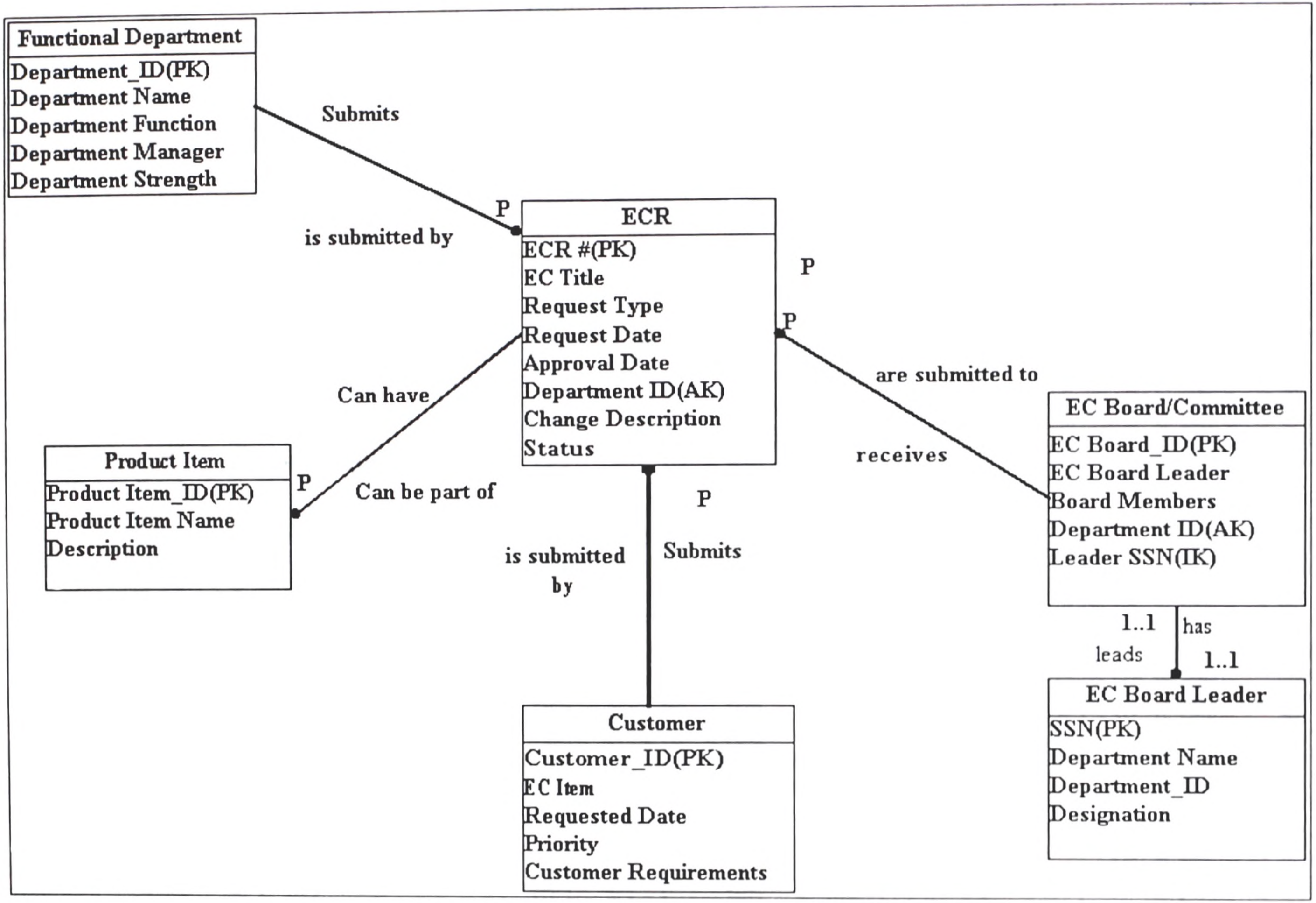


Figure 16: Object Class diagram of 'Request an EC' Use Case

Table 16: Attribute table of the object 'EC Quote'

Object Name	EC Quote
Definition	The quote/estimate given to a customer notifying the customer about the cost incurred to execute the change.
Attribute Name	**Definition**
Quote_ID (PK)	The unique identification number assigned to any EC quote. This will be the primary key of the object- EC quote.
Date Created	The date the EC quote was created.
Estimated Delivery Date	The estimated completion date of the EC.
EC Item Description	The description of the item for which the EC quote is requested.

Table 17: Attribute table of the object 'EC Item'

Object Name	EC Item
Definition	The EC item (product, part, component, subcomponent etc.) for which the EC is requested.
Attribute Name	**Definition**
EC Item_ID (PK)	The unique identification number assigned to the EC item. This will be the primary key of the object- EC Item.
Product Item_ID(AK)	The product to which the EC Item belongs to.
Product Item Name	The name of the product item to which the EC item belongs to
EC Item Description	The description of the item for which the EC is requested.
Change Type	Specifying the type of the EC
Version	The version of the EC item if it has previously undergone EC in the past.

Table 18: Attribute table of the object 'EC Review Report'

Object Name	EC Review Report
Definition	The review report depicting the possible impacts on the design, manufacturing processes, materials, lead-time, cost and quality due to an EC.
Attribute Name	**Definition**
Report_ID (PK)	The unique identification number assigned to the EC review report.
EC Review_ID(AK)	The review that results in the creation of the report.
Review Item	The description of the EC item that's being reviewed.
Review Type	States the type of review report: - design review, processes review, cost review, scheduling review.

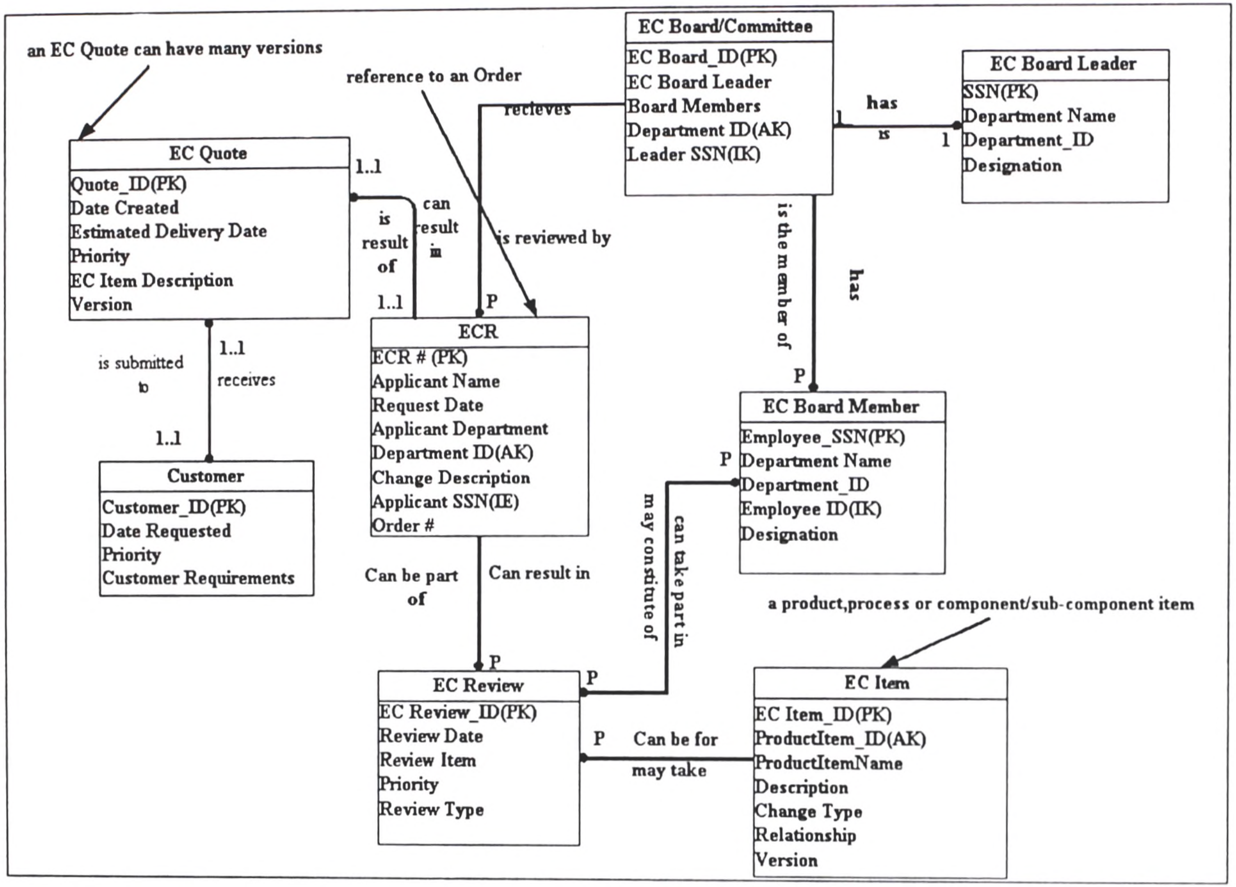


Figure 17: Object Class diagram of 'Review an EC' Use Case

Table 19: List of objects of 'Order an EC' Use Case

Entity name	Object Type
ECO	Entity
ECO Form (Interface)	Interface
Functional Departments	Entity
EC board	Entity
EC board leader	Entity

Table 20: Attribute table of the object 'ECO'

Object Name	ECO
Definition	An ECO is the official order issued to functional departments to implement an EC in technical terms and with customer specifications.
Attribute Name	**Definition**
ECO_ID (PK)	The unique identification number assigned to the ECO-primary key.
ECO name	The name of the ECO in technical terms.
EC description	The description of the EC in terms of customer requirements, customer specifications, implementation details etc.
Receiving Department(s)	The functional department(s) responsible for executing the change.
Change Type	The type of EC.
Start Date	The date when the EC should be started to be incorporated.
End Date	The final delivery date of the EC with the expected result.

Object Class diagram for 'review an EC'

Figure 17 shows the object class diagram for the activity 'review an EC'. An ECR can be initiated for a particular order represented by the object attribute order #. The order # refers to a particular order for an EC. One ECR can result in one or one to many EC quotes given to the customer, defined by the attribute version #. An ECR is also related to an EC item in the sense that one ECR can be initialized for one or one to many EC items.

Table 21: Attribute table of the object 'Product Item'

Object Name	Product Item
Definition	The product, part, component, sub-component that has to undergo the EC.
Attribute Name	**Definition**
Product Item_ID (PK)	The unique identification number assigned to the product Item-primary key.
EC Item _ID (AK)	The identification number for an EC item.
Product Item Name	The name of the product/part/component/sub-component.
Description	The description of the product item undergoing the change.
Change Type	The type of EC.
Version	The version of the product item undergoing the change if at all it has gone changes previously.

Object Class diagram for 'plan for EC'

Refer to Figure 18 for the object class diagram of 'plan for EC/create an ECO' Use Case. One engineering change item can have one or one to many product items. For example an ECR is requested for change in the specifications of a particular component (EC Item), which in turn consists of one or more sub-components (product items) then this ECR will address the need for change of all the constituting components and sub-components. On the other hand a particular component/subcomponent during its manufacture must have been made of one and only engineering process.

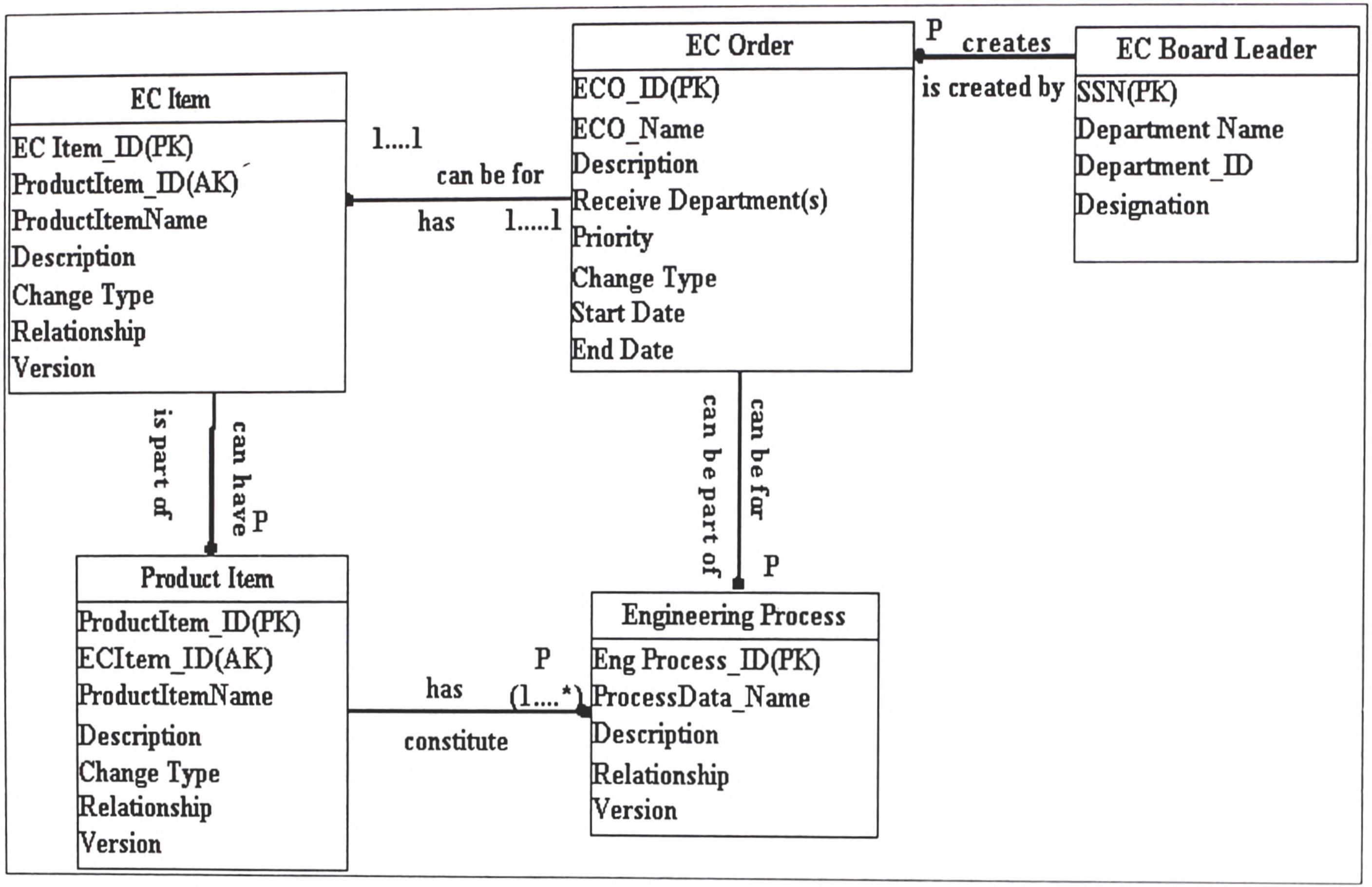


Figure 18: Object Class diagram of 'Plan for EC/Create an ECO' Use case

Table 22: List of objects of 'Deploy an ECO' Use Case

Entity Name	Object Type
ECN	Entity
EC Progress Report	Entity
EC Progress Report Interface	Interface

Table 23: Attribute table of the object 'ECN'

Object Name	ECN
Definition	The notification issued by the functional department or the EC project owner notifying all the concerned departments and the EC board about the complete implementation of the EC Project.
Attribute Name	**Definition**
ECN_ID (PK)	The unique identification number assigned to ECN-primary key.
Part	The part for which the EC project was initiated.
Process	Process for which the EC project was initiated.
Description	The description of the product/process item that underwent the change.
Process/Project Owner	The person/functional department responsible for executing the change.
ECN version	The version of the ECN undergoing the change if at all it has been previously modified.
Action Taken	The implementation details to completely implement the EC.
Date Issued	The Date the ECN was issued.

Object Class diagram of 'execute engineering change'

After executing an EC the participating or the implementing functionality creates the ECN depicting the implementation details of the EC. The EC project/process owner, the part for which the change was executed and the date when the ECN was issued are one of the most critical attributes that define them.

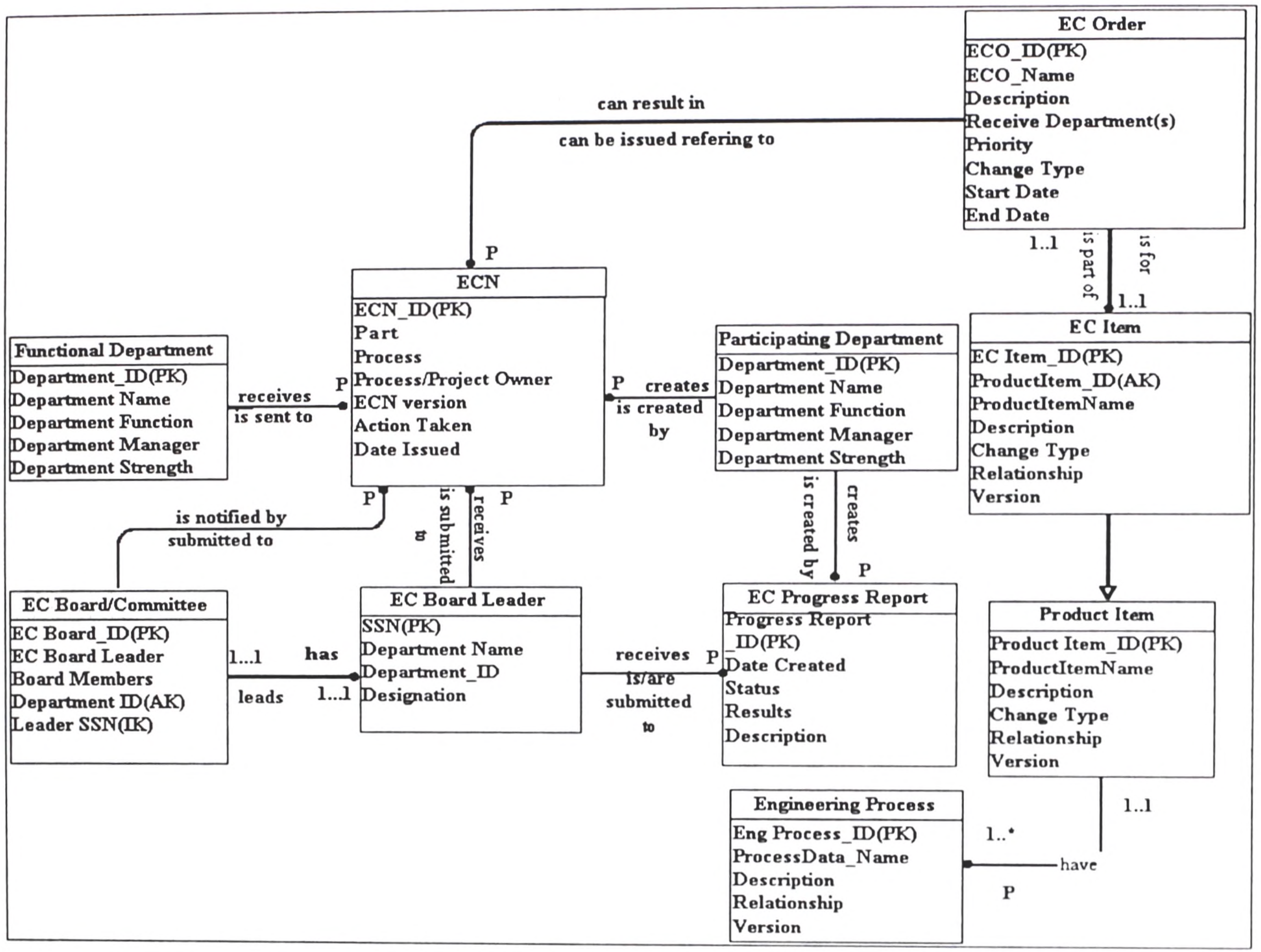


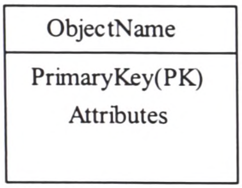
Figure 19: Object Class diagram of 'Execute the EC' Use case

Table 24: List of objects of ‘Conduct Post-Implementation Assessment’ Use Case

Behavior/Entity name	Object Type
EC Result Report	Entity
EC Result Report Interface	Interface
Post-Implementation Assessment	Entity
EC Result Report	Entity

The object class diagrams of all the use cases mentioned above are put together to create the object class model for ECM. The complete object class model of ECM is shown in Appendix D. Thus the object model is based on all the data entities already identified by the activity model right from the activities constituting the EC process to the objects involved in those activities. Shown below are the cardinality conventions followed for the object class model of ECM and the individual object class diagrams.

Table 25: Symbols and Cardinalities for ‘Object class model for ECM’

Symbol	Object Type
	Entity
Cardinality Notations	
	One-to-one or many
	One-to-exactly N Where N = 1….n

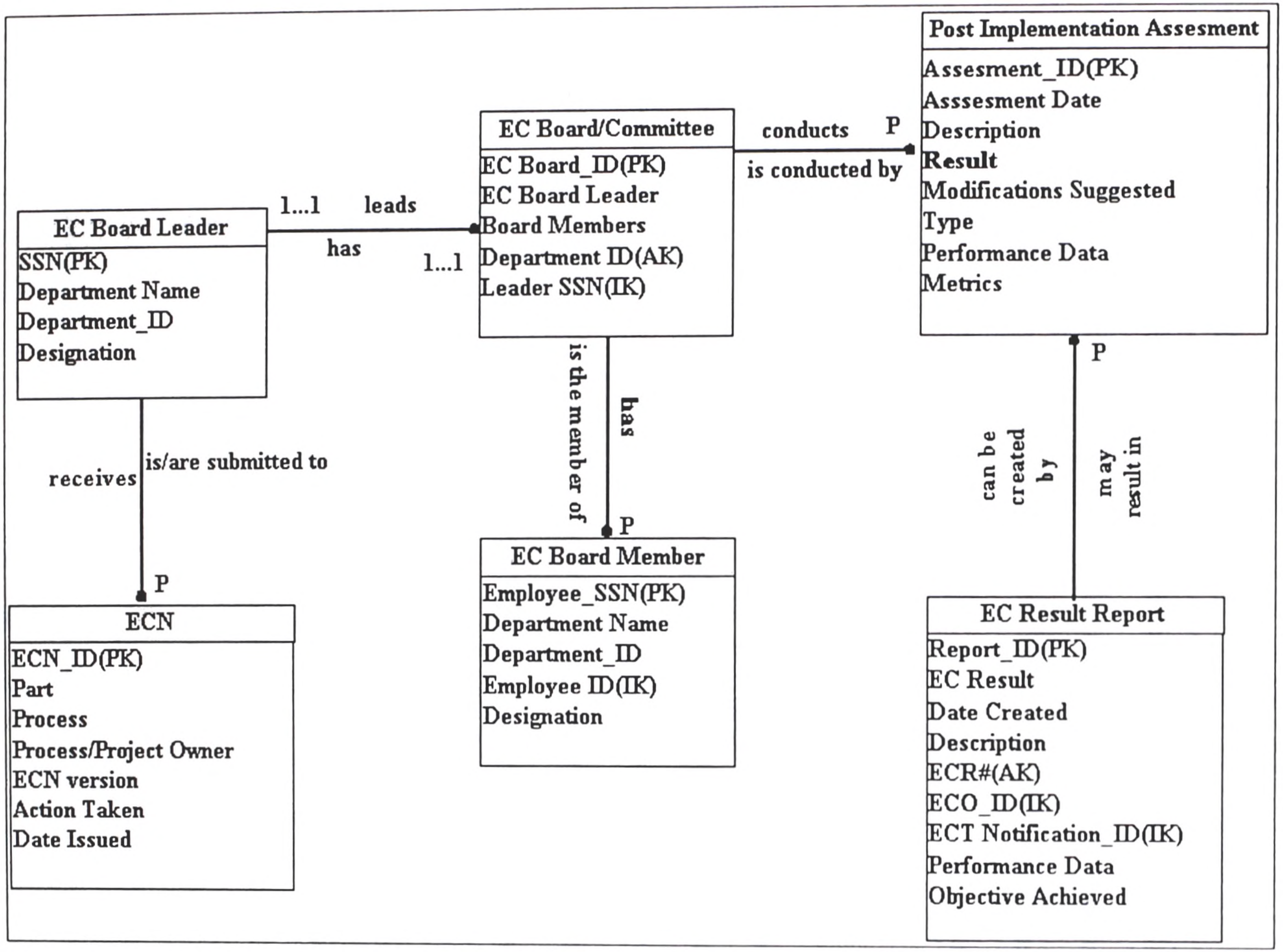


Figure 20: Object Class diagram of 'ECN'

3.6 DYNAMIC MODELING

Object class modeling examines the static structure of the ECM system by just identifying the structure and the relationships (cardinalities) of the engineering change process objects. However, dynamic modeling addresses the dynamic behavior of objects identified in the object model (refer Appendix D) via the different events that take place while executing an EC right from 'request an EC' to 'Post-Implementation Assessment', and associated state changes that can happen to an object during different execution states.

3.6.1 Framework for the Dynamic Model

Please refer to the framework for the dynamic model in Appendix E. Every object and actor in the framework of the dynamic model is accompanied by its symbol. The leftmost column shows the activity flow of all the business activities for executing an EC. The process starts with an ECR put forth by customer(s) (Actor1) and any functional department (Actor 2) after identifying it. Both the actors mentioned above are also objects and in addition to this there is also the ECR which can be identified as an object. The status of the object ECR can be identified as submitted, reviewed and approved/rejected. Customer requirements, EC result, engineering requirements and order specifications are the inputs to the object ECR. The second activity will be the 'EC review' also will be carried out by the actors as shown in the framework. The EC review is also an entity object and goes through the following states of manufacturing process review, materials review, quality review, scheduling review and cost review. Please refer to the inputs and the outputs to every object which are a part of the EC review. The next logical activities of creating an ECO, routing the ECO to functional departments, are also identified with its objects, actors, inputs and outputs. Implementing the EC is characterized by the following objects: - functional departments, ECN and EC progress report. Please refer to the comments column to check the functionality of every object and its output.

3.6.2 State Diagrams

State Diagrams are drawn for objects to depict the status of the objects during their life cycle right from their birth to their termination. Different events take place to trigger a change in the state of a particular object. A state diagram that links states through events describes the behavior of a single class of objects. Each event corresponds to the method of the object. This research has captured the dynamics of critical objects in the engineering change process from the activity model and translated them to state diagrams. Figure 21 shows the different states through which the object ECR goes through during its life cycle right from its creation by the customer or by a functional department. Figure 22 shows the object life cycles of the object ECO. Figure 23 shows the object life cycle of the object ECN and Figure 24 shows the object life cycle of 'EC review'.

Object Life Cycle	Actor(s)	I/P Data	O/P Data
New ECR	Functional Department, Customer	EC Result, Order Specifications, Customers' Requirements	ECR
Reviewed for Design	Engg & Design	ECR	Design Changes
Reviewed forManufacturing processes	Production	Design Changes Manufacturing Process Data Tooling Information	Manufacturing Process Changes
Reviewed forMaterials	Inventory Control	BOM	Modified BOM
Reviewed for Quality	Quality Control	Modified BOM	Quality Changes/Impacts
Reviewed for Lead-time	Manufacturing.	Lead-Time Data	Effects on Lead-Time
Technically feasible (No → Rejected; Yes)			
Reviewed for Cost	Finance, Purchasing.	Cost Data Supplier Quotes Customer Reimbursement	EC Quotes/estimates Modifications to ECR
Economicaly feasible (No → Rejected; Yes) / Rejected	EC Board	Infeasibility Data: Technical, Economical	Rejected ECR
Approved	EC Board	EC Result, Order Specifications, Customers' Requirements	Approved ECR

Modifications to ECR

Figure 21: Object life cycle of 'ECR'

Object Life Cycle	Actor	Trigger	I/P Data	O/P Data
New ECO	EC Board Project / Process Owner	Approval of ECR	Customer Specifications	ECO Document with implementation Details
Planned Scheduled Released	Project / Process Owner	Approval of ECR	EC Related Data Product Platform and architecture manufacturing process information Pert /Gantt charts	Allocated Resources Approval Information Product-Processchange matrix BOM system level design change
Implemented	Functional Depts./ project Owner allied entities	Approved ECO	Implementation Details	ECN

Figure 22: Object life cycle of object 'ECO'

Object Life Cycle	Actor	Trigger	I/P Data	O/P Data
New ECN	Functional Dept.	Implemented EC	Changed Specifications. Implementation Details	EC Result EC progress Report
Reviewed	EC Board, Functional Departments	Created ECN	Performance Data Changed Specs.	Modifications
Approved	EC Board	Reviewed ECN	EC Goals& Objectives	EC Result Report

Figure 23: Object life cycle of object 'ECN'

Object Life Cycle	Actor	I/P Data	O/P Data
New EC Review	EC Board	EC Goals and Objectives Customer Requirements	
Conducted-Design/ Specifications Review	Engineering and Design	Customer Specifications	Changed Specifications
Conducted-Process Review	Production	Manufacturing Process Data Tooling Information	Process Changes
Conducted-Materials Review	Inventory Control	BOM	Modified BOM Materials Changes
Conducted-Quality Review	Quality Control	Quality Standards	Quality Impacts
Conducted-Scheduling Review	Manufacturing	Lead-Time Data	Sceduling Impacts
Conducted-Cost Review	Finance,Purchasing	Cost Data Customer Reimbursement	EC Quotes Approved ECR Rejected ECR
Approved	EC Board	Technical/Economical Feasibility Data	EC Quotes ECO

Figure 24: Object life cycle of the object 'EC Review'

3.6.3 Sequence Diagrams

Sequence Diagrams are used to depict the interaction between various objects in terms of events/activities that relate them. In other words they represent detailed activities depicting the role of the objects in those activities. Please refer to Appendix A for the sequence diagram of 'Request an EC'. The actor initiating the event, that is a customer or any functional department requesting the EC, logs in with user name and password using the form to check-in as part of the ECMS. At the back end the log-in information is verified, which logs the user in. The actor selects the option of 'Make an ECR Proposal' from the options form of ECMS. The form is displayed. The actor fills in all the relevant information for the new ECR, namely customers requirements, the expected EC result, the engineering requirements and order specifications. This EC related data is saved in the EC database under a unique ECR proposal number.

Appendix A shows the sequence diagram of 'EC review and EC execution'. The actor in this sequence of events is the EC board leader. After logging in with the user name and password the actor selects the 'EC review and ordering'. The EC board leader will select the particular ECR for which the EC board leader wants to view the EC review report. After the system displays the contents of the ECR the EC board leader selects the option to view 'Review Reports' prepared by the respective departments. Also please observe the back-end operations of the EC repository. The EC board leader depending on the view of the EC committee approves the ECR and inputs the approbation command. The approbation result is saved in the EC repository. The system in response to this creates the ECO with all the technical details and implementation details attached to it. The EC board leader then routes the ECO to the related disciplines or departments to be implemented with the implementation details. The routing information along with all the relevant EC details is saved in the EC repository.

Appendix A shows the sequence diagram of 'EC Review Report' and 'EC Progress Report' creation. The functional department head (user) or the person responsible for preparing these reports will log-in. The user will the select the option of create an 'EC Review Report' fill in the data of the type of the review conducted and would save the details of the EC review. The routing information will be used to route the EC review report to the concerned departments and the EC board as part of the EC review.

3.7 SUMMARY

The development process starts with the PD process which we believe is the foundation for the EC process. The triggers to engineering changes are shown as different types of changes at the various product development stages. Then the overall development of the model is explained with the functional requirements of an engineering change process is mentioned. The development of the model starts with the mapping of the basic activities of the engineering change process starting with requesting an engineering change, reviewing the engineering change, planning for the change and executing it. The modeling starts with use case modeling where all the use cases pertaining tò these activities are enumerated. These use cases are then used to develop the activity models where IDEF0 diagrams have been used to depict every activity in its functional form. Thus the final IDEF0 model ECM shown in Figure 11 has achieved the objective of capturing the EC process and the EC data in its functional form. The criterion of dividing the business process into its hierarchical activities and sub-activities was satisfied. All the data entities from the object model are identified and then defined in terms of their attributes (Table 7 through Table 24). Simultaneously object class diagrams are drawn for every activity of the activity model and the cardinalities are identified. Thus this chapter culminates with the completely developed object class model for engineering change management. Dynamic modeling starts by depicting state diagrams for the following objects: - ECR, ECO, ECN and EC review. The state diagrams depict the object life cycle right from its birth till the culmination of the object life. The actors responsible for the change in the state of these objects are also identified along with the input data, output data that trigger the event causing a change in the state of the object. Sequence diagrams are used to show the interaction between objects and the events that trigger them. Appendix A shows all the sequence diagrams.

CHAPTER

IV VALIDATION

The information model developed in this research is validated in terms of its objectives that were achieved. The results of this research are compared against the objectives of this research. The prime objective of this research was to capture the EC process flow and data to guide the execution of EC. Use case modeling was used to develop an activity model. The activity model mapped the whole business process of managing engineering changes right from 'making an ECR', reviewing the ECR, plan for ECO and to execute the EC. Every activity and sub-activity which is an inherent part of the process of EC was identified along with the inputs that go into that activity, the outputs of the activity/sub-activity, the controls within which the activity has to be executed and the mechanism.

Another objective of this research was to capture the EC data. Data flow to every activity was identified in the activity model. The object class model was developed form the activity model wherein critical objects were identified and were defined in terms of their attributes. Tracking of these critical objects is facilitated by the object class model and the dynamic model for the users of an ECM system. Another objective of this research was to capture the life cycle of objects critical in the EC process. Defining the inter-relationships amongst these objects was also an important parameter. This was achieved by the dynamic model depicting the life cycles of critical objects namely: - ECO, ECN and ECR. It also identified the actors who trigger a change in the state of the objects and the input data which trigger these changes in state. The cardinalities between these objects showed the interdependencies amongst these objects.

The other important objective of this research was to achieve process integration in managing ECs. Process integration was achieved by the activity model which streamlines all the constituting activities of managing ECs and the information related to these changes.

CHAPTER

V CONCLUSION

This chapter concludes this research in two sections. The section 5.1 summarizes the development work of the research and section 5.2 discusses about the future work. The literature review has shown that although much attention has been given to the procedural management and administrational issues of engineering changes, there has been no work contributed to capture the essence of engineering change management in its true sense. There has never been a generic model proposed to guide the execution of engineering changes in terms of activities, entities (objects) and the states of these critical objects.

5.1 SUMMARY

This research focused on the development of an information model for managing EC. This goal was achieved by developing a model based on standardized modeling techniques like IDEF0 and IDEF1X, to develop 'activity model' and 'object model'. This work was successful in providing a generic information model which focused on the business process of executing an EC in terms of its constituting hierarchical activities and sub-activities. Inputs to every function (activity), outputs of every function and the mechanisms that stand for resources to perform those activities (functions) were also identified. The object model identified all the objects in the EC process that are part of the activity model and defined them in terms of the objects' attributes. The cardinality of the objects shows the relationships these objects have with each other. The dynamic model captured the object life cycle of the objects in an EC process. The dynamic model also captured the status change of critical objects and the actor (who does it). The dynamic model also identified the input and the output data responsible for triggering the event that brings the change in the state of the object. This information model captures all functional participants of an engineering change process along with the information flow related to each one of them. Therefore it can also be said to be a generic model that can serve as an appropriate platform for developing an enterprise system for engineering change management.

5.2 Future Work

The future work addresses the issue of refining the model to make it adaptable to a collaborative environment. The very basic approach of this research was to bring and align the engineering change process as close as possible to the product development process. A generic model was developed for the engineering change process of a manufacturing company.

5.2.1 Refinement of the Information model

There are a few aspects which could be considered for refining the information model. The next logical questions that arise are:-Can the present model be refined so as to handle engineering changes when the product development involves multiple manufacturing organizations? Can this model be used in a collaborative environment? If yes, how different will the informational model be for such a scenario? How will the business process of executing an engineering change in such a multi-company setting vary? Will the engineering change information flow as identified in the activity model of this research be any different? Will the dynamics of such an information model be the same? The answers to these questions can be used to polish the information model developed in this research.

5.2.2 Proposed System Architecture

The other obvious and logical concern would be to propose a system architecture using the features of the information model developed. The whole architecture can be composed of three parts, refer Figure 25.

The Central Project Database: - The heart of the model as shown in Figure 25 is a 'Central Project Database'. The project database can consist of three parts 'EC database', 'Product design database' and 'Product components database'. The product components database functions as a repository for all the design data that are necessary to describe every product component in an EC project. This will include all the units which make up the product. The product design database acts a repository for all the design information of the product, i.e. the product architecture. It will describe the major units and the functional parts of the product. The EC database is a repository of all the ECs executed till date and all the relevant information corresponding to it and documentation, design information and also information required for managing the various functions of the information model. There will be two sub-systems of the architecture the EC manager system (for the EC Team) and the EC Execution system (functional participants). The whole system is a modularized system wherein every module which will be a part of either the EC manager system or the EC Execution system will be linked to the central database through SQL.

EC Manager System: - The EC board leader who is responsible for the overall execution of the EC is linked to the central project database through a group of modules called the 'EC manager system'. The EC manager system will also be linked to a general database of the organization. The EC manager system will consist of the EC Ordering module, EC tracking module, EC mapping module and the EC review module.

EC ordering module will address the functionality of EC ordering. The EC board leader orders an EC through the EC ordering module. This module will create an Engineering Change Order (ECO). After the EC team review, when the engineering change order has to be created to meet the goals and objectives of the EC, the EC team leader will create an ECO by specifying the departments to whom the ECO should go to and then submit it to the system.

EC review module will address the functionality of EC review. This module will be able to capture all the decisions made by the EC board as a result of the EC review and the post-implementation Review.

EC mapping module will address the functionality of EC routing. The functionality of EC mapping module for instance can be routing ECOs and ECNs (activity A4- in the activity model) to the respective departments responsible for deploying the EC.

EC tracking module will address the functionality of EC tracking. This module will be able to track the progress of every EC that is undertaken by the concerned departments/disciplines. The EC board leader will be able to query the status of any EC that is carried out.

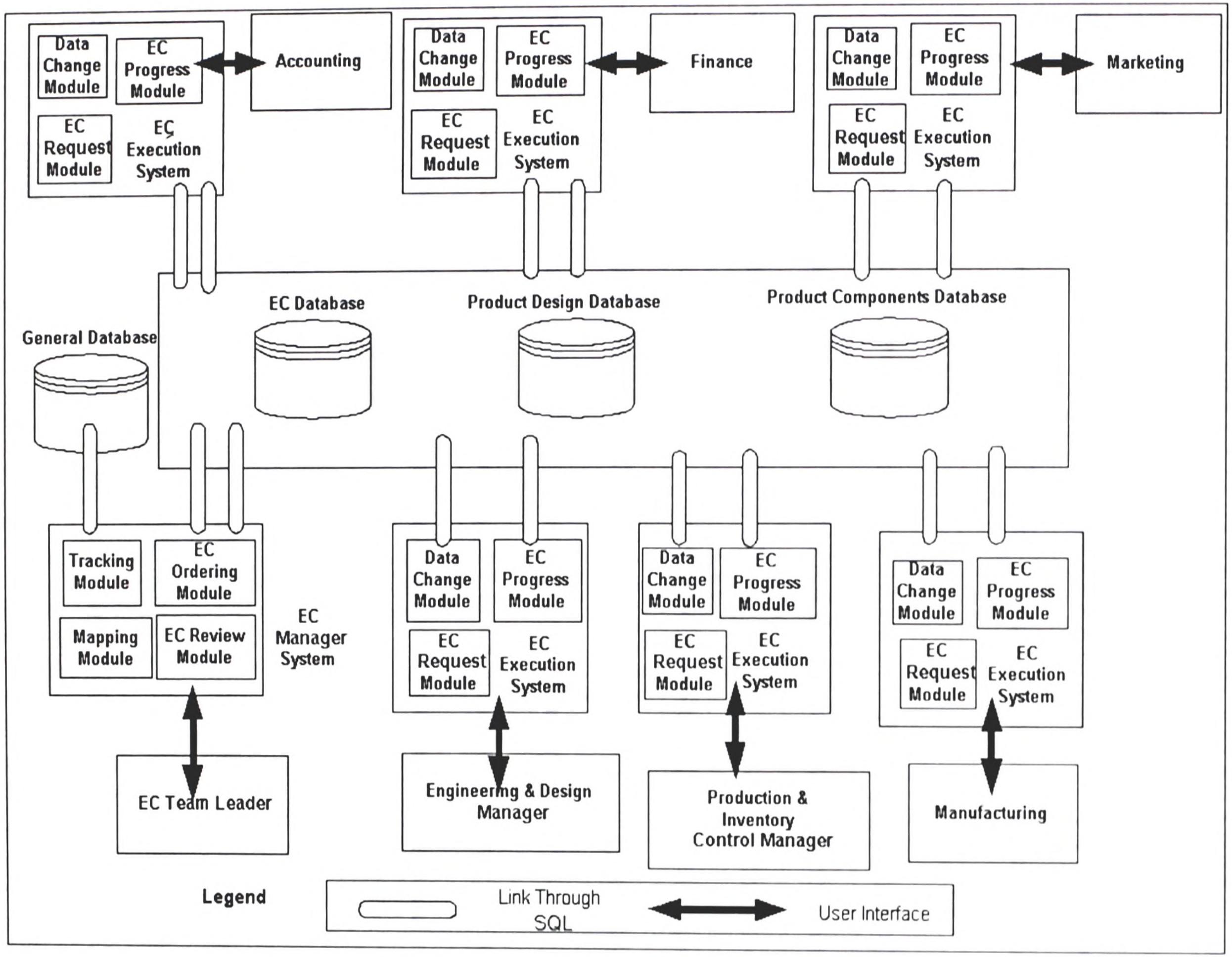


Figure 25: Overview of the Proposed System Architecture

EC Execution System: - This system will be used by those contributing disciplines who will be responsible for deploying the EC and the once who could put forth the EC request for executing the EC to the EC team. The EC execution system can be spread over the following departments, since these are the functions that play a vital role in executing any EC in most of the organizations (Diprima, 1983):- Engineering and Design, Production and Inventory Control, Manufacturing, Marketing, Finance & Accounting.

EC request module will address the functionality of EC requesting. Customers and functional department heads from the various departments through this module can submit a new ECR to the EC board. EC data change module will address the functionality of EC Implementation. Functional departments can change/modify the data of the product or any EC data pertaining to any EC through this module. EC progress module will address the functionality of EC progress tracking. Through this module the EC participants could prepare EC progress reports to be submitted to the EC board and related functionalities. Thus the implementation of the above architecture can be said to be an extension of the research.

5.2.3 Implementation Issues

This information model can be used as a basis to implement and develop an Enterprise System for Engineering Change Management. The following section describes the requirements for implementation in an engineering environment:-

- Manage the EC data pertaining to the product (product structure, components etc.) in a collaborative environment.

- Link different computers available in different functional departments in order to facilitate processing of ECs.
- A centralized system of data whereby all the relevant EC information can be stored thereby supporting collaborative ECM activities.
- Provide access security to authorized persons. As these people can be internal-EC board members, functional department heads or external-customers, suppliers etc.
- Provide a notification service to report requesting, authorizing, approving, releasing and completing ECM activities.
- The system should be based on database programming. The system should be based on object-oriented databases.
- The computer aided system should be based on the client/server architecture.
- The EC system should be modularly built-wherein one module specializes in one set of related functions- ordering EC, approving/authorizing EC, routing EC and reviewing EC.
- To support interoperability in a heterogeneous environment, the system can be implemented based on the concept of CORBA (Common Object Request Broker Architecture).
- Future work should be carried out to design the system and implement it in a three-tier layered architecture based on the technology of distributed objects and CORBA.
- The first logical step would be to develop a prototype engineering change management system in a virtual engineering environment.

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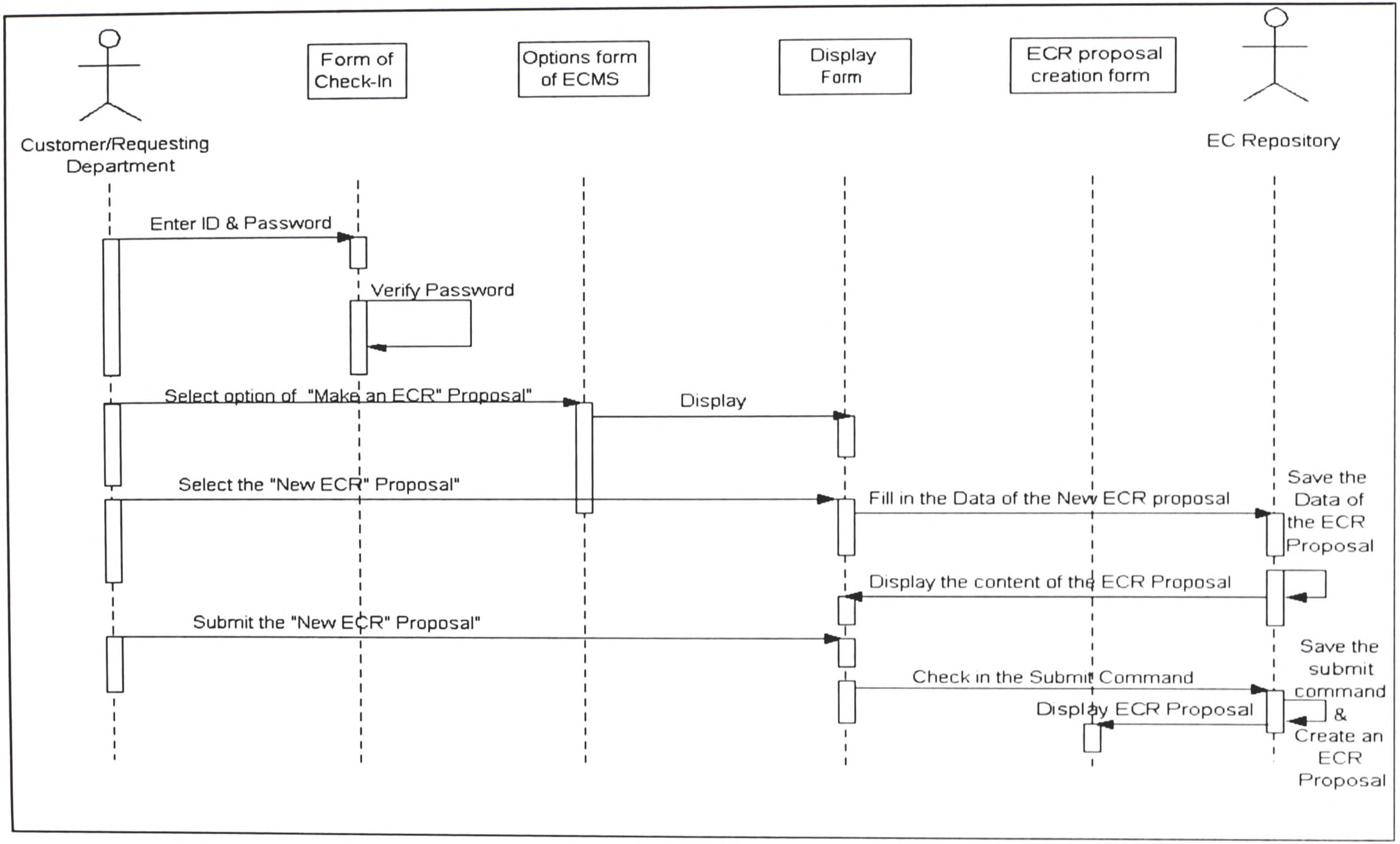
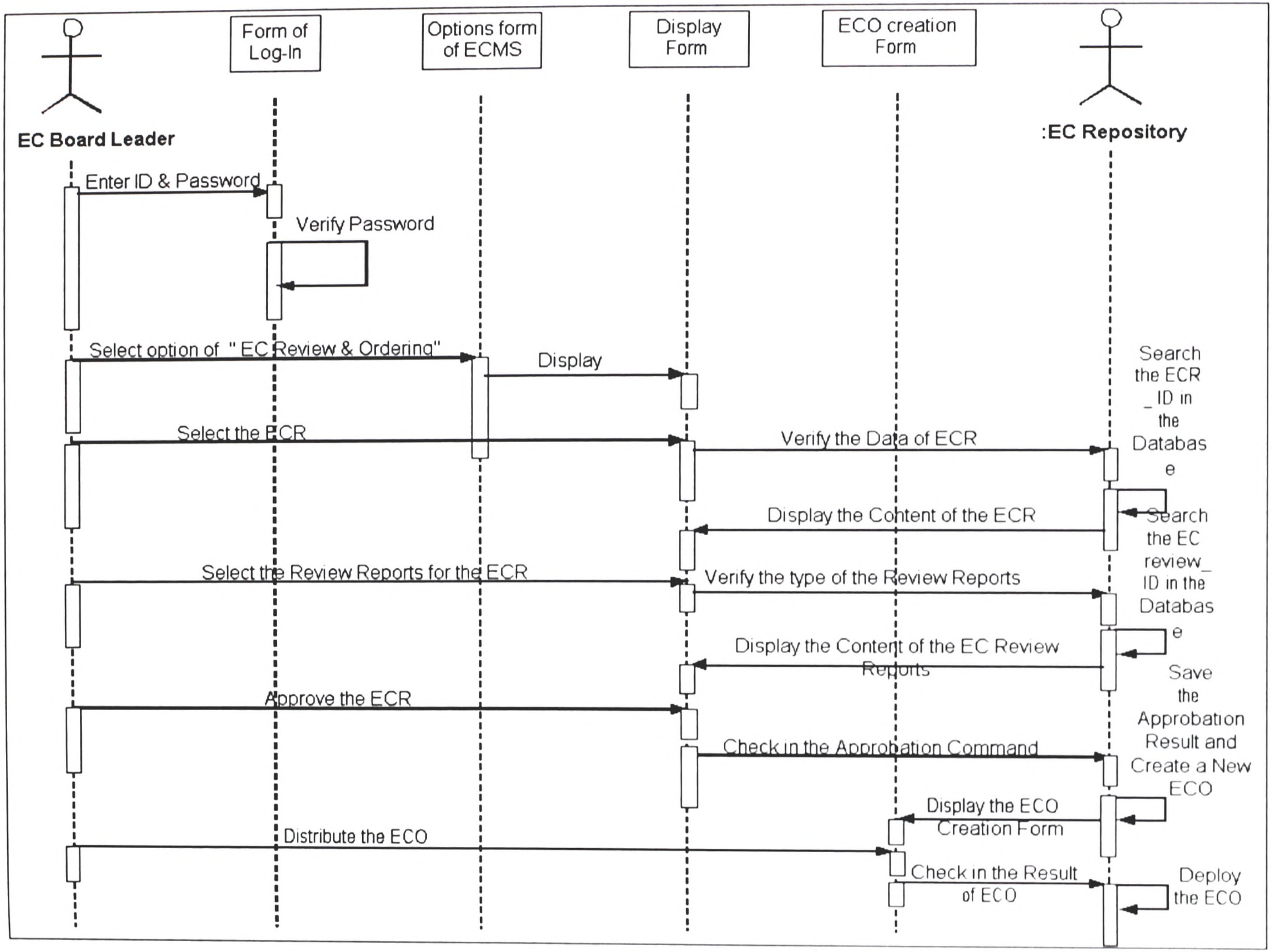
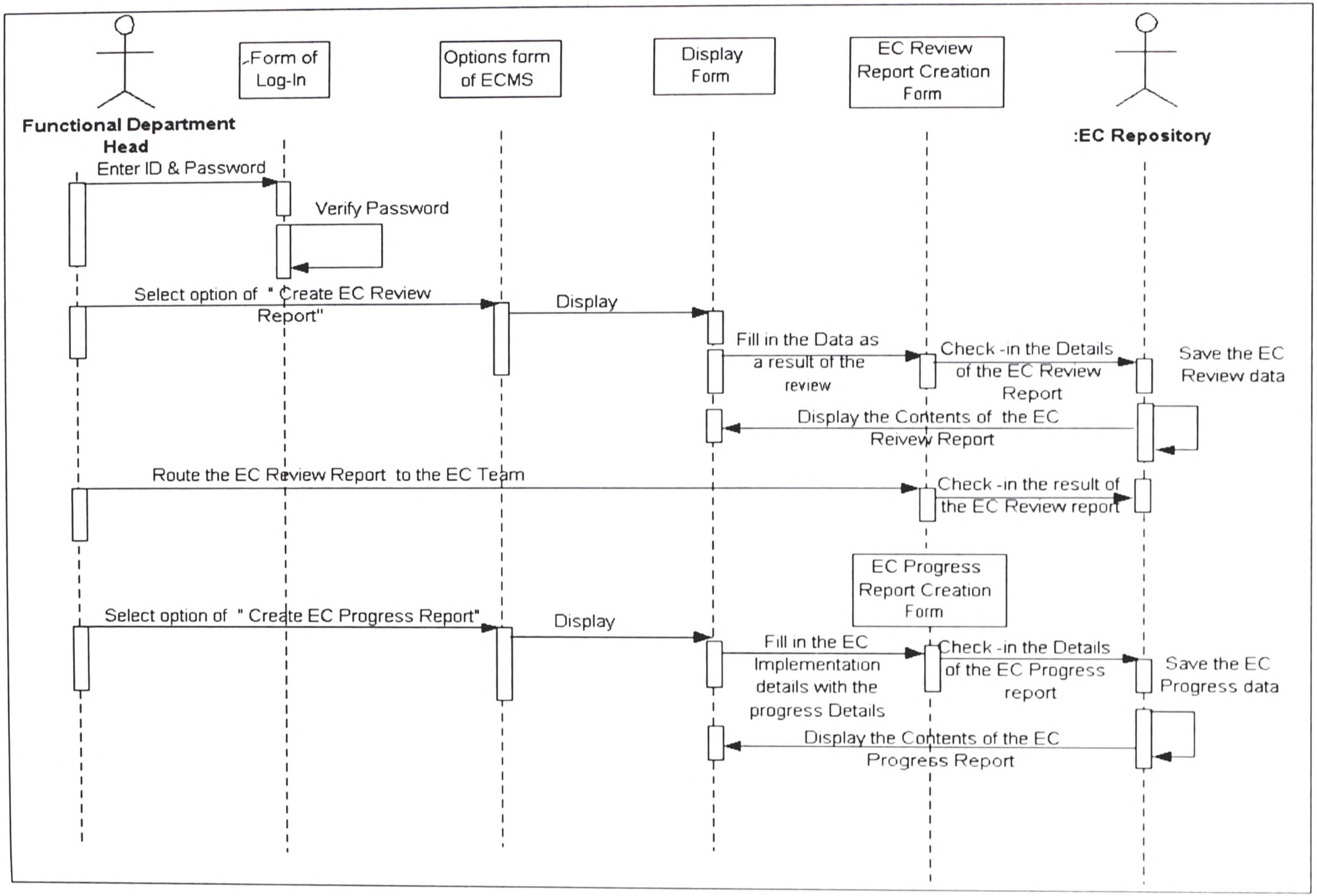
APPENDICES

APPENDIX A




Form of Log-In
Options form of ECMS
Display Form
ECO creation Form
EC Board Leader
:EC Repository
Enter ID & Password
Verify Password
Select option of " EC Review & Ordering"
Display
Search the ECR _ ID in the Databas e
Select the ECR
Verify the Data of ECR
Display the Content of the ECR
Search the EC review_ ID in the Databas e
Select the Review Reports for the ECR
Verify the type of the Review Reports
Display the Content of the EC Review Reports
Save the Approbation Result and Create a New ECO
Approve the ECR
Check in the Approbation Command
Display the ECO Creation Form
Distribute the ECO
Check in the Result of ECO
Deploy the ECO


Form of Log-In
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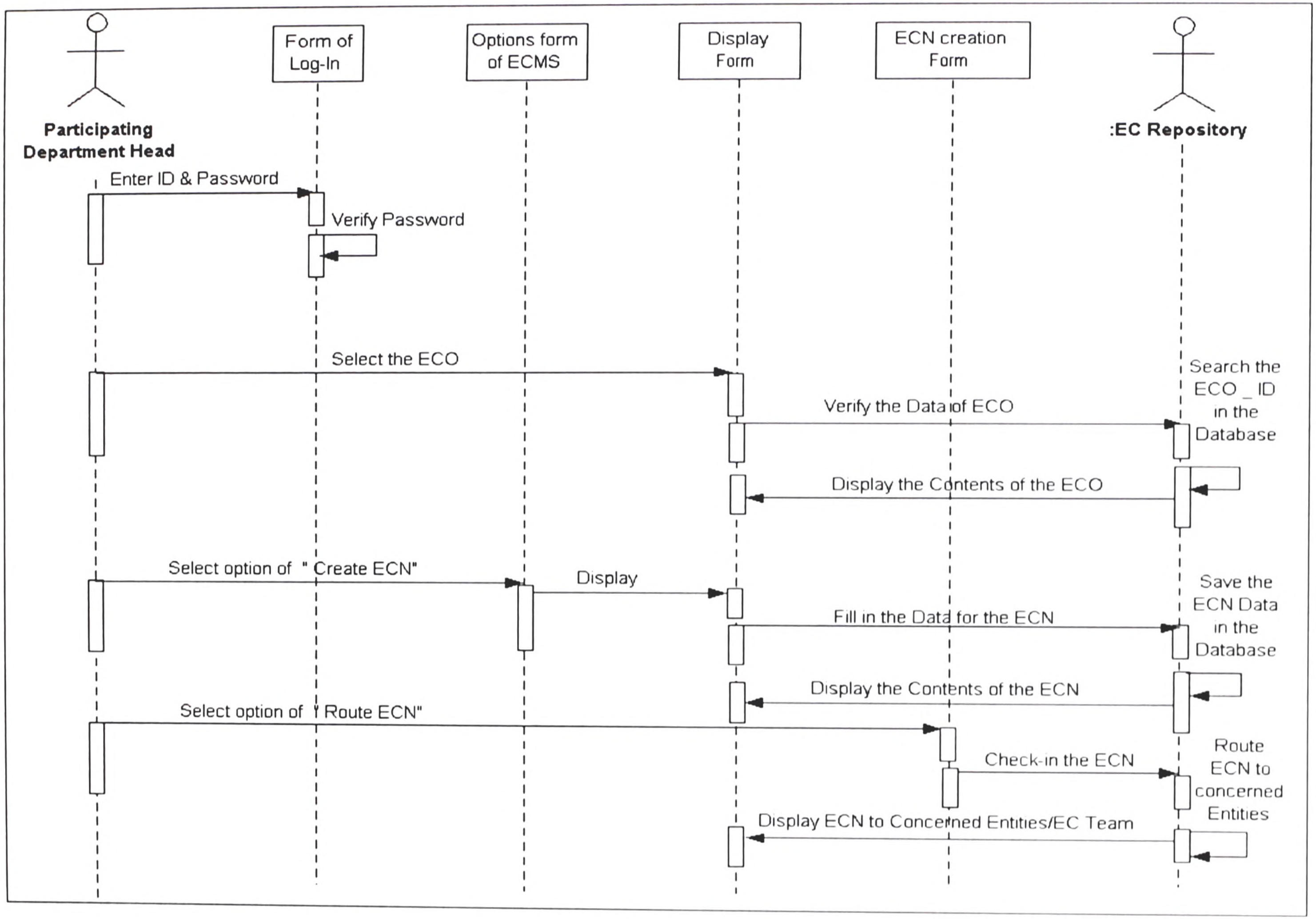
Display Form
EC Review Report Creation Form
Functional Department Head
:EC Repository
Enter ID & Password
Verify Password
Select option of " Create EC Review Report"
Display
Fill in the Data as a result of the review
Check -in the Details of the EC Review Report
Save the EC Review data
Display the Contents of the EC Reivew Report
Route the EC Review Report to the EC Team
Check -in the result of the EC Review report
EC Progress Report Creation Form
Select option of " Create EC Progress Report"
Display
Fill in the EC Implementation details with the progress Details
Check -in the Details of the EC Progress report
Save the EC Progress data
Display the Contents of the EC Progress Report


Form of Log-In
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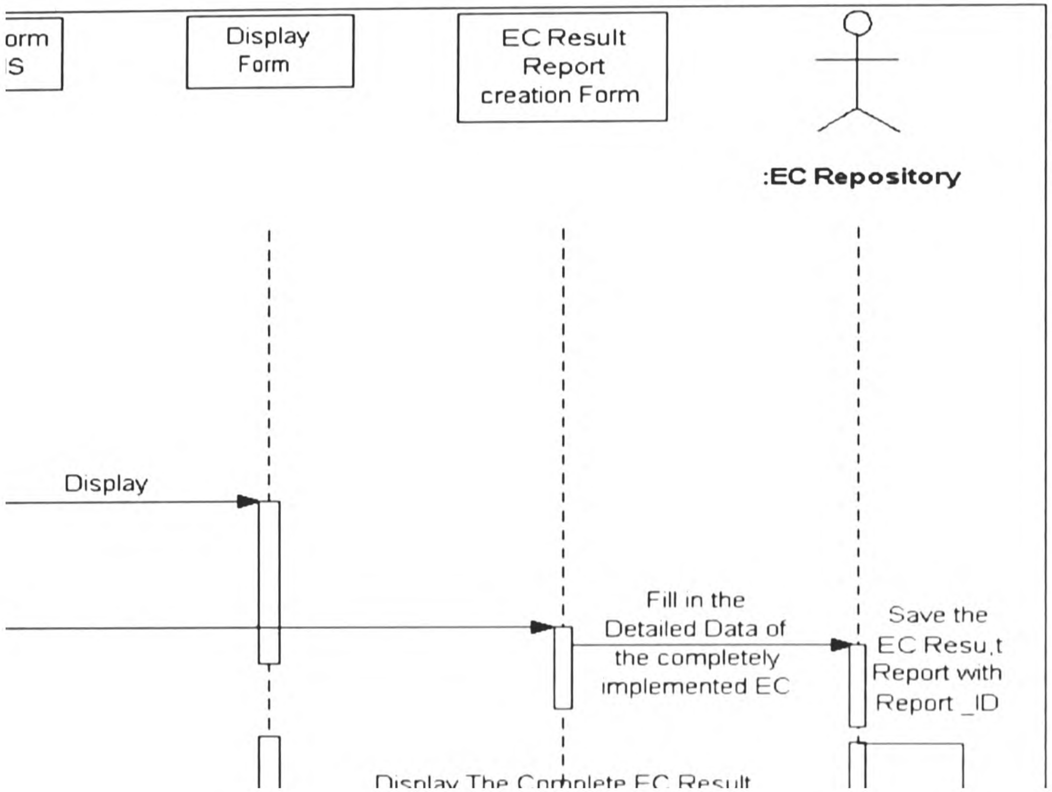
Display Form
ECN creation Form
Participating Department Head
:EC Repository
Enter ID & Password
Verify Password
Select the ECO
Verify the Data of ECO
Search the ECO _ ID in the Database
Display the Contents of the ECO
Select option of " Create ECN"
Display
Save the ECN Data in the Database
Fill in the Data for the ECN
Display the Contents of the ECN
Select option of " Route ECN"
Route ECN to concerned Entities
Check-in the ECN
Display ECN to Concerned Entities/EC Team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Fill in the Detailed Data of the completely implemented EC
Save the EC Resu,t Report with Report _ID