ENTERPRISE COLLABORATIVE PORTAL FOR BUSINESS PROCESS MODELLING

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SUMMARY

The business processes of manufacturing enterprises have to be dynamic, especially when highly customised products are manufactured or different projects run simultaneously. Another trend in contemporary manufacturing is the necessity for co-operation between geographically dispersed teams. This research presents a new method for modelling business processes enabling co-ordination of dynamic workflows.

This thesis focuses first on Business Process Modelling (BPM) techniques and outlines the limitations of the existing methodologies. Similarly, an overview of Enterprise Collaborative Portals (ECP) is conducted and a method for collaborative authoring of dynamic workflows is discussed.

Next, the thesis introduces the concept of business process models with feedback based on the Product/process (P/p) methodology. An extension to this methodology, validated through a case study, is developed to overcome some of its limitations. The performance of the proposed extension is analysed and compared with that of the Unified Modelling Language (UML) and its advantages are highlighted. The case study used to demonstrate the capabilities of the proposed approach involves the development of a golf training device prototype using Rapid Prototyping technology. The proposed process modelling methodology is validated in PTC Windchill ™ EIMS, which also serves as a platform for the implementation of the enterprise collaborative portal.

The thesis also proposes a benchmarking method for business processes based on the work of Spendolini and the extended P/p methodology. Benchmarking factors are

identified and the proposed benchmarking methodology is validated with an example. The benefits of the proposed benchmarking methodology are outlined.

Finally, a method for modelling business processes enabling co-ordination of dynamic workflows is presented. The same case study is used to illustrate the algorithm for collaborative authoring of the business process model. As a platform for the implementation of the proposed method, an object-oriented architecture is adopted.

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DECLARATION AND STATEMENTS

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

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ABBREVIATIONS

AHP	Analytic Hierarchy Process
API	Application Programming Interface
B2B	Business-to-Business
B2C	Business-to-Consumer
BPD	Business Process Diagram
BPM	Business Process Modelling
BPR	Business Process Re-engineering
CAD	Computer-aided Design
CBR	Case-based Reasoning
CIM	Computer Integrated Manufacturing
CSV	Comma Separate Value
ECP	Enterprise Collaborative Portal
EIMS	Enterprise Information Management System
EIP	Enterprise Information Portal
EOS	Electro Optical Systems
ERP	Enterprise Resource Planning
EWP	Enterprise Web Portal
FDIS	Final Draft International Standard
HTML	Hypertext Mark-up Language
IGES	Initial Graphics Exchange Specification
ISO	International Organisation for Standardisation

IT	Information Technology
JSP	Java Server Pages
OCL	Object Constraint Language
OMG	Object Management Group
PCD	Process Chain Diagram
PDM	Product Data Management
P/p	Product/process (methodology)
PTC	Parametric Technology Corporation
RP	Rapid Prototyping
SADT	Structured Analysis and Design Technique
SLS	Selective Laser Sintering
SQL	Structured Query Language
STL	Stereo Lithography
UML	Unified Modelling Language
WWW	World Wide Web
XML	Extensible Mark-up Language

Chapter 1 - Introduction

1.1 Motivation

Enterprise business processes need to be very dynamic in order to respond to the changing manufacturing requirements of products. A product often has to be manufactured in different ways to address customer requirements, which leads to different business process models. Moreover, an enterprise generally deals with many projects at the same time, starting simultaneously and requiring different process models. In some cases customers require modification of an existing product. This leads to changes in the manufacturing processes and hence to business process re-engineering.

Enterprises face a dilemma in satisfying customers' demands for reduction in lead-time, simultaneously with increasing demands for highly customised products and services. For an enterprise to be successful in such environments, it has to establish a corresponding culture for continuous improvement and be supported by responsive business processes [Tam et al. 2000].

Unlike office processes or routine tasks in finance and other administrative departments, most manufacturing related processes are highly dynamic, not well structured, and in need of frequent modification. Therefore, business process modelling tools should contain process descriptions, preferably in graphical form, that are easy to modify and that allow the generation of new process models automatically on the basis of existing ones [Grigorova 2001].

Numerous business process modelling (BPM) tools are now available. However, most BPM tools are not able to conduct "what if" scenario analysis, show dynamic changes in business processes, or evaluate the effect of stochastic events and random behaviour of available resources [Irani et al. 2000]. A graphical tool is required that can model the dynamics of processes and then show them visually. This will allow the participants in such business processes to generate creative ideas when redesigning existing business processes. There is a need to develop process modelling tools that are underpinned by a systematic methodology.

Another aspect of contemporary manufacturing enterprises is the need for interdisciplinary teams to collaborate and for their activities to be co-ordinated. When a project team is located at more than one site, it is very difficult to synchronise their tasks and optimise the usage of these distributed resources. Therefore, it is essential that all participants contribute to the creation of the process models in the early stages of the project [Vernadat 1996]. In addition, such geographically dispersed teams need a suitable interactive environment to model business processes concurrently. The objective of such collaborative model development is to enable teams to improve their business processes and shorten product lead-times.

Currently, a major concern in industry is the inter-operability and consistency of business processes in relation to enterprise integration. The provision of efficient process co-ordination in large distributed business environments is the key to achieving the required level of inter-operability. To address these requirements, formal methods for building computer-processable models have to be developed together with techniques/tools that allow all participants in a business process to contribute towards its creation.

The Internet has stretched business processes across the traditional organisational boundaries, so that several enterprises could be involved in one business process. Examples of this include collaborative forecasting, vendor managed inventory, distributor/reseller (Business-to-Business - B2B) management and the traditional buying and selling (Business-to-Customer - B2C) applications. Enterprise portals provide solutions for this higher level integration of users and enable efficient business process control. To achieve such integration, the Internet features of these portals are combined with enterprise information authoring and management systems, such as Computer-Aided Design (CAD), Product Data Management (PDM), and Enterprise Resource Planning (ERP), to create Enterprise Web Portals (EWP). The aim is to provide users of such systems with the right information at the right time and in the right format anywhere within the extended enterprise [Rezayat 2000b].

Typically, organisations use portal and Intranet systems as a means to reduce internal information publishing costs and enhance the access to information by all users. Portal design can be more ambitious than this by providing functionality that helps small and large groups of people to work together more efficiently. There is also a consensus that tight integration between suppliers and customers throughout the entire product development cycle is essential.

Many tasks in business process re-engineering projects are common or similar in different business activities. Thus, by identifying these common requirements it is possible to propose generic enterprise modelling and integration frameworks. Such frameworks will capture, standardise and re-use tools for solving common business modelling and integration tasks, instead of developing them again from the beginning each time. Once standardised, generally accepted frameworks can be supported by models and methodologies, leading to time and cost savings. Such standard models could be stored and then reused in new situations by applying case-based reasoning techniques.

1.2 Objectives of research

The scope of the research reported in this thesis is the provision of collaborative authoring of dynamic business process models in large distributed business environments. The overall aim is to provide a methodology for the collaborative distributed development of dynamic manufacturing workflows. This research attempts to overcome the problems faced by the geographically dispersed teams when working on joint projects with respect to business process model creation, communication and co-ordination issues.

The individual research objectives of the project are:

1. To provide a methodology that overcomes some of the shortcomings of the existing business process modelling approaches and provides the required functionality.

2. To create a benchmarking methodology for business processes based on the proposed approach.

3. To create a case base of standard process models, which can be reused by applying case-based reasoning techniques.

4. To develop an approach for collaborative creation of business process models involving members of geographically dispersed teams.

5. To develop a distributed business environment based on the Enterprise Collaborative Portal that enables collaborative authoring of dynamic workflows.

1.3 Outline of the thesis

The main body of the thesis comprises Chapter 2 to Chapter 5. Chapter 2 is a review chapter. Chapters 3-5 address the objectives listed above. Finally, Chapter 6 summarises the contributions and conclusions of the work and makes suggestions for further research.

Chapter 2 consists of three reviews, which provide background knowledge for Chapters 3-5. The first review discusses existing business process modelling techniques, in particular the Product/process (P/p) methodology and the Unified Modelling Language (UML). The second review is dedicated to Case-based reasoning techniques (CBR). The third review focuses on Enterprise Collaborative Portals (ECP) and the services provided by them.

Chapter 3 addresses research objective (1). It starts by presenting the limitations of the existing process modelling techniques, in particular the P/p methodology. Several extensions to this methodology are developed to overcome some of the limitations and the proposed improvements are discussed in detail together with a case study used to validate them. The performance of the proposed extensions to the P/p methodology is analysed and compared with that of the Unified Modelling Language (UML) for this case study. Finally, conclusions are made about the suitability of these extensions for business process modelling and their advantages related to UML.

Chapter 4 focuses on research objective (2). It proposes a benchmarking methodology for business processes based on [Spendolini 1992] and the extended P/p methodology.

Firstly, the benchmarking factors are identified and then the suggested methodology is discussed in detail. Next, the benchmarking methodology is validated through an examination of the variation of quantitative data for cost, time and quality by changing some process attributes for the same business process that was used as a case study in the previous chapter. Finally, the benefits of the proposed methodology are highlighted.

Chapter 5 addresses research objectives (3), (4) and (5). It starts by proposing a solution for the creation of business process models involving members of geographically dispersed teams. A method for modelling business processes enabling co-ordination of dynamic workflows is discussed in detail. Next a distributed business environment based on the Enterprise Collaborative Portal that enables collaborative authoring of dynamic workflows is developed. As a platform for the implementation of the proposed method, an object-oriented and agent-based architecture is adopted. Finally, the ability proposed solution is demonstrated to facilitate the creation of a new business process model, as well as the re-engineering of existing processes based on the created case base and supported by a case-based reasoning tool followed by generation of workflows to validate these models. The proposed method for collaborative authoring of dynamic manufacturing workflows is validated. The validation results are based on the use of the Windchill EIMS ™ from Parametric Technology Corporation [PTC 2001], which also serves as a platform for the implementation of the Enterprise Collaborative Portal.

All the examples in Chapters 3-5 used to illustrate the proposed solutions are based on a case study involving the development of a golf training device prototype by employing Rapid Prototyping technology.

Finally, Chapter 6 summarises the contributions and conclusions of the presented work and suggests possible directions for further research in this area.

Chapter 2 - Review of Process Modelling Techniques, Case Based Reasoning and Enterprise Portals

In Chapter 1, the need for dynamic business processes for manufacturing enterprises was identified especially when highly customised products are manufactured or when different projects run simultaneously. Another trend in contemporary manufacturing involves collaboration between geographically dispersed teams. In this chapter a review of existing business process modelling techniques is conducted, together with an overview of enterprise collaborative portals. Two business process modelling techniques are presented in detail – the Product/process (P/p) methodology and the Unified Modelling Language (UML). An overview of the case-base reasoning techniques is also included to support the proposed solution presented in subsequent chapters.

2.1 Business process modelling

Enterprise Business Processes need to be very dynamic in order to respond to the changing requirements for the manufacture of the product. A product often has to be assembled in different ways to suit customer requirements, which leads to different business process models. Moreover, an enterprise generally deals with many projects at the same time, which start simultaneously and require different business process models. In some cases customers require modification of an existing product, which leads to changes in the manufacturing processes and to Business Process Re-engineering.

Hence, there is a dilemma – on the one hand customers demand that their orders are fulfilled very quickly, whilst on the other hand they require highly customised products and services. For an enterprise to be successful it has to establish a corresponding culture and be supported by responsive business processes [Tam et al. 2000].

Traditional business process automation tools, such as workflow management systems, are often considered to be an ideal solution to manage such dynamic processes. However, traditional process modelling creates an abstract representation of processes that is analysed off-line; similarly, a workflow management system addresses only steady-state flow with pre-determined control decisions or user-based control. Currently available systems have no capability for proactive or dynamic scheduling and control [KTI 2001].

[Paolucci et al. 1997] and [Tumay 1995] argue that one of the problems that makes business processes difficult to modify is the lack of simulation tools for evaluating the effects of potential solutions before implementation. There is also thought to be a lack of appropriate design, methodology and modelling tools [Irani et al. 2000].

Another aspect of contemporary manufacturing enterprises is the need for teams to collaborate and for their activities to be co-ordinated. It is essential that all participants contribute to the creation of the process models at an early stage of the project [Vernadat 1996]. These geographically dispersed teams need a suitable interactive environment to model business processes concurrently. The objective of such modelling is to enable teams to improve their business processes and shorten their development time.

2.1.1 What is a Business Process?

According to [Vernadat 1996], business process is a sequence (or partially ordered set) of enterprise activities, execution of which is triggered by some event and that will result in some observable or quantifiable end result.

A process model is an abstract description of a real-world process representing process steps considered important for the purpose of the model. A process can be enacted by a human or machine, or both.

Another definition of a business process, suggested by [Hammer and Champy 1994], is: "A business process is a collection of activities that takes one or more kinds of input and creates an output that is of value to the customer. A business process has a goal and is affected by events occurring in the external world or in other processes."

According to [Davenport 1992], "A process is simply a structured set of activities designed to produce a specified output for a particular customer or market. It implies a strong emphasis on how work is done within an organisation, in contrast to a product's focus on what. A process is thus a specific ordering of work activities across time and place, with a beginning, and end and clearly identified inputs and outputs: a structure for action."

Therefore, "A business process is an abstraction that shows the co-operation between resources and the transformation of resources in the business. It emphasises how work is performed rather than describing the product or services that result from the process" [Eriksson and Penker 2000].

A process can be classified according to the nature of the activities that are carried out. If the nature of the activity is physical, such as assembling a product, that process is considered a material process. If its nature is about processing information, such as calculating the price of a product, then it is an information process. If its nature is about doing something with information, such as making a commitment to a supplier to pay for a product, then the corresponding process is called a business process [Hommes 2001].

Often "core" and "supportive" business processes are distinguished. A core (or primary) process is initiated from outside an organisation, e.g. the chain of activities that realises the delivery of a product to a customer. A supportive (or secondary) process is initiated from inside the organisation to provide support for core processes, e.g. buying new stock from a supplier.

2.1.2 Business Process Attributes

According to [Kaposi and Myers 2001], processes are systems, whose representation is characterised by an interrelated collection of attributes, transforming an input product into an output product over a period of time. Therefore, the attributes characterising a process should include:

- The **duration** – the time period of the operation, given as a constant or as a variable;
- The **domain** of valid input products;
- The **transfer function** - a function over the measures of the attributes of the input product to produce the measures of the attributes of the output product;
- **Status** – if the process is free or busy at the time of the input product arrival;
- The **owner** of the process, if man-made;
- The **agent** – the means by which the process is executed;
- The **cost** incurred by executing the process, if the process is man-made.

Consider the process attributes in more detail. Since every process takes some time to be executed, the duration of the process is a very important attribute. It may be explicitly set in advance, or be bounded so that the process is completed within a certain interval.

Since every process has its limitations, it is important to set up the domain of the process. Defining the domain of acceptable inputs is necessary for the protection of the products and processes. The domain may be defined by enumeration, restricted by defining the attributes of the input to be included or excluded.

The transfer function defines the relationship between the attributes of the input and the attributes of the output. According to [Kaposi and Myers 2001] processes may change the value of attributes; generate new attributes; suppress attributes or perform some combinations on the above.

At the instant of arrival of the input product, a process must be free and not engaged in an operation on the previous input. Therefore, the status attribute is a binary number: its value is "free" when the process is free and is set to busy for the period in which the process is unable to accept a new input.

According to fundamental principles of management and quality assurance [Kaposi and Myers 2001], the responsibility for a given process should rest with an individual and not be divided. Most processes however are too complex for the owner to execute alone, so that tasks or subprocesses are delegated to different individuals, while the owner retains overall responsibility for the successful execution of the process.

Another useful process attribute is the physical agent that carries out the process. The agent may be a person, a team, a machine or some composite mechanism. The agent is selected by the process owner to perform the task of carrying out the process.

Since all the processes absorb resources, the cost of a process is also a very important attribute. Usually material, physical and information resources, and people are involved in every process and their cost must be estimated in order to evaluate the overall process cost.

Taking into consideration all these observations, [Kaposi and Myers 2001] conclude that the condition for a process to take place is: "For a process to occur, the input product must be within the permissible domain of the process and at the time the product presents itself to the process the status of the process must be free".

2.1.3 Business Process Models

The relationship between business functions and business processes is often summed up in simple terms as follows: business functions describe what has to be done, while business processes describe how it must be done. The Business Process Model (BPM) is therefore used to model business processes, i.e. to describe how business functions are carried out [Hommes 2001].

A BPM can be represented in the form of various Business Process Diagrams (BPDs), such as PCD, SADT, Product/process graph, UML diagram, etc. Some examples of a BPD are presented in Chapter 3.

The components of the BPM depend on the particular modelling technique used, and the form of representation. Most BPM techniques comprise of activities, states (or events), organisational units and documents. The structure of the BPM is determined by directional links between states and activities. These directional links are represented in the BPD by arrows.

To ensure that the BPM remains comprehensible, it is possible to simplify matters by modelling at several hierarchical levels. When the structure is expanded into a hierarchy, the concept of the "subprocess" is introduced. The subprocess is an abbreviated representation of a process that occurs at a lower level in the hierarchy and which itself made up of a network of activities and states, and can be represented by a detailed BPD if required.

More specifically, the subject of this research is about business models. Business models are conceptual systems that stand for a special type of real system, namely a business system. "A business model is a conceptual system that corresponds to a business system, capturing those aspects of that system that are relevant for solving a particular problem" [Hommes 2001]. In general, representations such as diagrams, tables and text are used to represent and communicate the models, as illustrated further in Chapter 3.

2.1.4 Overview of Business Process Modelling Techniques

2.1.4.1 Business Modelling Technique Definition

Having defined the term "business model" in the previous section, the meaning of the term "business modelling technique" is addressed further. Descriptions of what a technique should be can be found in [Reijswoud and Dietz 1998] and [Seligmann et al 1989], however, there is no broad consensus. The definition of a technique, used here, is based on the description of it in [Hommes 2001] – "a technique is a well-defined set of rules and guidelines that support someone in accomplishing a certain task". This also holds for techniques in general: applying a technique is a matter of practice.

The task that a business modelling technique supports the accomplishing of, is the construction of models of business systems. Therefore:

"A business modelling technique is the set of rules and guidelines to support someone in constructing business models" [Hommes 2001].

A modelling technique is a description of how models should be constructed. It has a product-oriented and a process-oriented aspect. The product-oriented aspect describes the structure of the products that result from the modelling effort: the models. The product-oriented view is called the way of modelling of a modelling technique. The process-oriented aspect on the other hand, describes the process of constructing these models. The process-oriented view will be addressed as the way of working of a modelling technique.

The terms "way of modelling" and "way of working" are borrowed from a framework for analysing information systems development methodologies proposed by [Seligmann et al. 1989].

2.1.4.2 Aims of Business Modelling Techniques

According to [Hommes 2001], four different types of problems that are solved by modelling become apparent (applied to business models in particular):

1. **Abstraction** - a model is used to analyse a business system by means of abstracting the relevant features of that system;

2. **Simulation** - a model is used as reflection of the current state of affairs of the modelled business system, following the changes that take place;

3. **Prototyping** - a model is used to construct a prototype of a future information or business system that incorporates all the relevant features of that system;

4. **Realisation** - a model is used to describe certain laws or patterns in a compact way, for instance as formulas.

[Kaposi et al. 1994] gives a number of reasons why models are used. The correspondence of these reasons to the types of problems deduced from [Hommes 2001] is indicated by the number in brackets: to describe some existing system clearly and concisely (1); to describe the main characteristics of some future systems (3); to reason closely about a system and analyse it rigorously (1); to predict system properties reliably (3); to select an existing system to meet requirements, and choose judiciously among options (2); to design a system to given requirements (3) and to set examples and norms (4).

According to [Law 1988] models are used for four main reasons: as an abstraction to manage complexity (1); as a tool to express features of the design (3); to support the designer (3) and to support properties of the implementation of the design (3).

2.1.4.3 Overview and Limitations of Business Modelling Techniques

Traditionally, enterprise modelling has involved tools and models originating from software engineering (SADT diagrams, data flow diagrams, entity-relationship models) or that have been developed to assist CIM (Computer Integrated Manufacturing). These techniques represent activity modelling rather than process modelling. Alternatively, it is possible to use Petri nets, which model process behaviour in detail but fail to model information and organisational aspects [Vernadat 1996]. Object-oriented techniques could also be employed to model processes and data [Tam et al. 2000]. However, most of the work undertaken so far on enterprise modelling does not focus on resource management and results in non-executable models. There is a need to develop process-modelling tools underpinned by a systematic methodology.

The basic steps of the enterprise modelling process are shown in [Fig. 2.1] [Vernadat 1996]. Undoubtedly Business Process Engineering and hence Business Process Modelling performs a key role in the Enterprise Modelling process. Therefore, to be able to provide a better understanding of the overall enterprise model and its relevance to real world problems it is essential to address the issues concerning Business Processes.

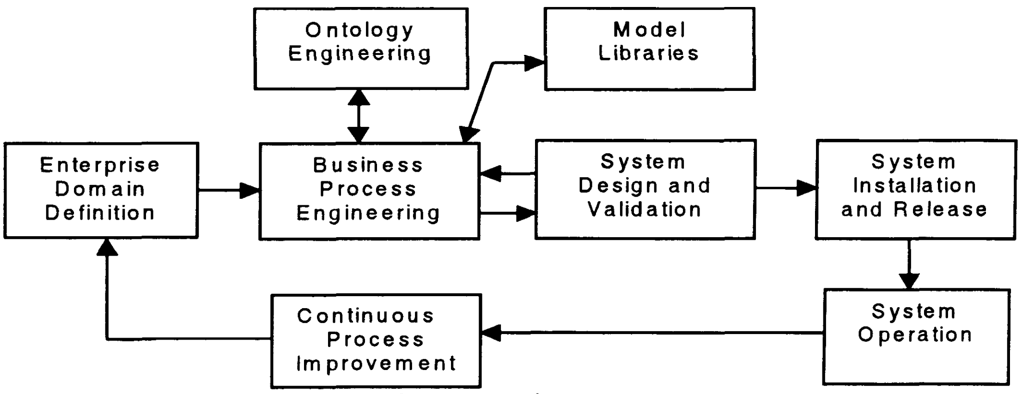


Fig. 2.1 - Enterprise modelling process [Vernadat 1996]

Currently, a major concern in industry is the inter-operability and consistency of business processes in relation to enterprise integration. The provision of efficient process co-ordination in large distributed business environments is the key to achieving the required level of inter-operability. To address these requirements, formal methods for building computer-processable models have to be developed. A methodology supporting the creation of such process models has to be agreed upon by all participants in the business process.

Numerous business process-modelling tools are now available. Many of these tools represent business processes graphically, where individual activities within the process are shown as a series of boxes joined by arrows. Some tools provide basic calculations of process times. Other, more sophisticated tools allow attributes to be assigned to activities and permit some process analysis. Most of these tools are not able to conduct "what if" scenario analysis, show dynamic changes in business processes, or evaluate the effect of stochastic events and random behaviour of resources [Irani et al. 2000]. There is a need for graphical tool that is able to model the dynamics of processes and then show them visually, enhancing the generation of creative ideas when redesigning existing business process.

Several reasons requiring innovation in business process modelling are given in [Tam et al. 2000]:

- Large companies run around 100 product design and development projects every year, i. e. there are always a large number of projects to be managed at any time.
- For various reasons it is not uncommon to see frequent ad hoc changes in design and delivery requirements during the course of a project. These frequent changes call for frequent re-scheduling and re-planning, which are time-consuming.
- More and more customers require information with regard to the time and cost breakdown of development projects. It would be beneficial to have a process planning

system that could provide such information to allow customers to customise the product based on their own lead time and cost requirements.

A product development project usually includes a set of work packages or activities that are executed by different personnel at geographically dispersed locations. To prevent inconsistency and reduce redundant activities, engineers must collaborate efficiently and project activities must be well co-ordinated. Therefore, there is a clear need for a mechanism to accomplish the co-ordination [Huang et al. 2000].

2.1.5 Discussion

The review of business process modelling techniques has highlighted two main problems:

1. Existing process modelling tools do not focus on resource management and tend to produce non-executable models [Vernadat 1996]. There is no efficient enterprise integration that addresses process co-ordination issues in large distributed business environments. A new methodology is therefore required for developing richer models, encompassing all aspects of enterprise modelling, including organisational aspects, resource management, product models and activity models.
2. There are no current solutions addressing the process modelling and co-ordination issues of dynamic workflows that could support geographically dispersed teams. To develop such solutions it is essential that all participants in a project contribute to the creation of the process model. An environment enabling collaborative work between globally distributed corporate partners is required [Firestone 1999].

2.2 Product/process methodology

2.2.1 Basic principles

The Product/process (P/p) methodology introduced by [Kaposi and Myers 2001] suggests a new approach for process modelling together with product data. The P/p methodology combines the concepts of the systems approach with those of the traditional engineering disciplines, the latter including rigorous models, measurements and quality management. Also it offers a "systems world view", which is equally helpful to clients, suppliers and users of complex systems.

[Kaposi and Myers 2001] introduce the basic principles of the P/p methodology:

- Principle 1 – Frugality;
- Principle 2 – Accessibility;
- Principle 3 – Clarity;
- Principle 4 – Rigour;
- Principle 5 – Selectivity;
- Principle 6 – Limited structure;
- Principle 7 – Concepts without tears.

2.2.2 Key concepts

The P/p methodology also introduces several key concepts including:

- **Referent** – any entity of interest in the real world;

- **Representation** – expression of ideas about the referent; in particular;
- **Modelling** – the activity of creating a purposefully simplified representation of the referent;
- **System** – representation of a referent by a set of interrelated entities;

Formally, **S=(E, R),** where **E** is a finite non-empty element set and **R** is a finite non-empty set of interrelations defined over the elements in **E**.

- **Black box** – representation of the referent as a set of interrelated attribute measures;

Black box system $S_b=(E_b, R_b)$, where E_b is the set of attribute measures and R_b is the set of interrelations which state temporal and referential cohesion.

- **Structure** – representation of the referent as a set of interrelated components;

Structural system $S_s=(E_s, R_s)$, where E_s is the set of component parts and R_s is the set of interconnections/interactions among the parts.

- **Product** - representation of a real life referent taken at a time instant;
- **Process** - representation of the referent over a time period of non-zero duration.

Product and process are systems, distinguished by their relationship to time. They may be represented as either a black box or a structure.

- **Time** is defined as an auxiliary concept – a characteristic common to all entities in the real world, either as position ("real time"), or as distance (time duration).

The syntax and semantics for the basic P/p methodology concepts with relevance to representation and modelling are presented in **Table 2.1** adopted by [Kaposi and Myers 2001].

Syntax	• "words" of the natural language, e.g. - product, - process, - "gate", - "product cluster", - "P/p graph"; • rules of combination - black box process, - process structures	• "words" of the artificial language of digraphs → ,etc. □ etc. (c) ,etc. • bipartite graph, • the algebra of product composition, • the algebra of process composition, ...
Semantics	• Informal definition of "words" (including auxiliary definition of "attribute", "measure", etc.)	• Formal definitions • Table for each labelled entity, • measures
Pragmatics	• representation	• modelling

Table 2.1 - Languages of the P/p methodology

2.2.3 Products and processes

The distinction between the product and process is fundamental for the problem solver. The following are definitions given by [Kaposi and Myers 2001]:

- The notion of both "product" and "process" is based on the concept of "system";
- "Product" is defined autonomously, without reference to the process that brought it about;
- The definition of "process" relies on the definition of "product";

- The distinction between "product" and "process" is based on the measure of time duration, "product" being instantaneous (having zero duration) and "process" having finite non-zero duration.

Gates have products as inputs and outputs, but they do not operate on their input to create their output and have zero duration. They can be of two types: collection gate (has two or more inputs and a single output) and distribution gate (has a single input and two or more outputs). **Valence** of a gate is the measure of the number of arcs incident on a node of a graph.

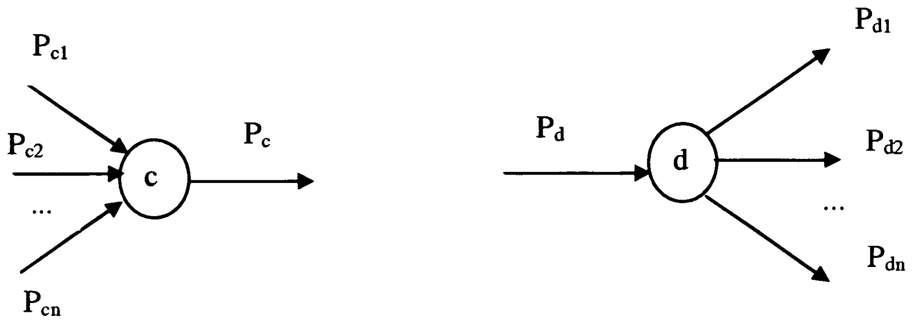


Fig. 2.2 - Collection and distribution gates of valence n +1

Timing – the state of a gate is either open or closed and gates change instantaneously. The normal state for a gate is closed and when it opens it is only for a time instant. If a gate is opened at time instant t_{in}, then t_{in} is the common time stamp of the input and output products of the gates, as in [Fig. 2.3]

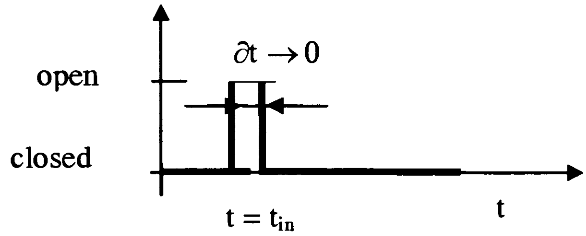


Fig. 2.3 - Gates and time

2.2.4 Product/process model

According to the P/p methodology, P/p graphs applicable to problems in any domain are used to model processes. These graphs are equally suited to represent problem referents, the process of problem solving and a solution when it is introduced into service.

P/p graphs are representations of active referents' operation. They make the characteristics of products and processes explicit. There are three kinds of P/p graphs [Kaposi and Myers 2001]: P/p networks, P/p frameworks and P/p models, defined as follows:

- **P/p network** – an acyclic b-type network where each arc is a placeholder for a product or a product cluster and each node is a placeholder for a process or gate;
- **P/p framework** – a P/p network representing a class of referents where
  - classes of products and processes given as black boxes are characterised by their well defined attributes, variable types and bounds;
  - classes of products and processes given as structures are constructively defined;
  - classes of product clusters are given as sets of product classes, and gates are characterised by their rule.
- **P/p model** – a P/p framework representing an individual referent, where products and processes are characterised by their attribute values.

The main elements of P/p graphs are products, represented by arcs and processes by single input and output nodes. [Fig. 2.4] shows the simplest P/p graph – a single process **p** with its input (**P_1**) and output (**P_2**) products.

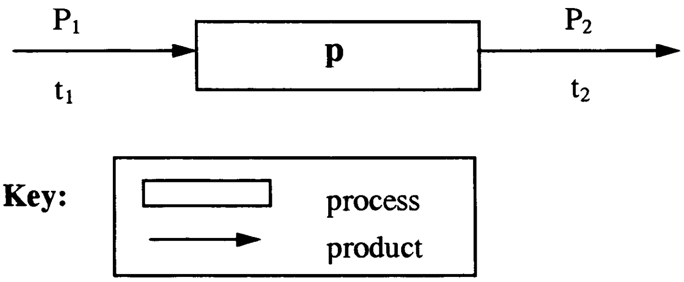


Fig. 2.4 - Simple P/p graph

P/p graphs are constructed using the following kinds of components:

- Products and product clusters, shown in the arcs of the graphs representing a referent carrying a real time stamp;
- Processes, shown as single input and output nodes, representing a referent as an activity over a time period;
- Gates, shown as nodes of degree three and more, could be collection or distribution gates.

The general keys for P/p graphs are given in [Fig. 2.5]. A P/p graph is a tool for modelling systems, expressing the ideas of individuals, facilitating communication between interested parties, analysing, designing and developing systems, and reasoning about them. Thus, the P/p methodology serves as an appropriate tool for business process modelling, especially because of its ability to identify entities which need describing or whose attributes need defining and measuring.

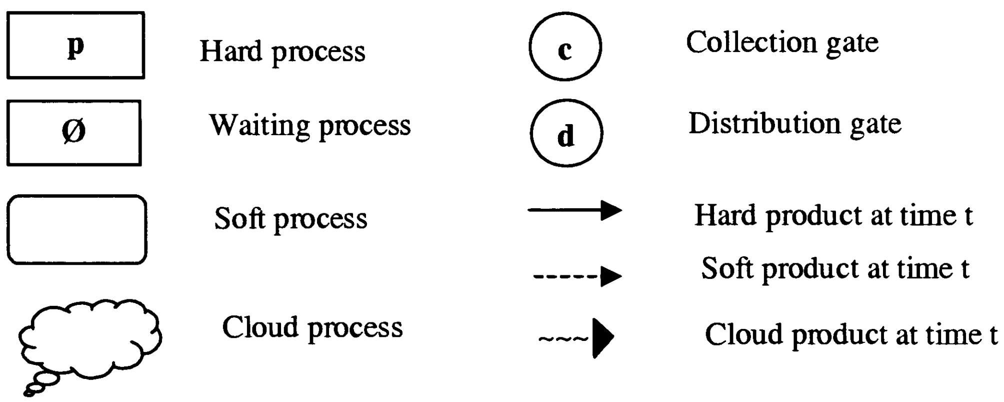


Fig. 2.5 - General keys for P/p graphs

2.2.5 Discussion

In the previous section a review of a recent business modelling technique was carried out. After careful consideration of the P/p methodology two main limitations were encountered, namely:

1. The time stamp of the product is assumed to be zero, which is not true in practice. The time stamp is defined as a time measure, which is a characteristic common to all products in the P/p graph. Products should be modelled according to the requirements of their real time requirements. Therefore, different time stamps should be assigned to them, since their attribute measures undergo changes at different time instances;

2. There are no feedback operators in P/p graphs – the modelling tool of P/p methodology. As currently formulated the P/p graph must be free of feedback because it would imply simultaneous presence at a process input of two products with different time stamps. Therefore, a proper formalism for representing feedback would

be required in the P/p model to be able to demonstrate the real behaviour of the business process. The P/p methodology can accommodate feedback of the kind used in continuous systems, which is a useful shorthand representation of repeated single-shot processes in discrete systems.

Obviously, the described process model can be improved by applying a few additional components in the P/p graph and a few new concepts in the P/p methodology. Firstly, feedback could to be incorporated into the model of the process. Secondly, when the feedback is applied then the same product will have two (or more) different time stamps. Therefore a cyclic graph is required. It is important to arrange the time stamps of the product properly; also time duration for a product could be used.

2.3 Overview of the Unified Modelling Language (UML)

Another widely used business modelling technique is the Unified Modelling Language. The Unified Modelling Language (UML) was created by Booch, Rumbaugh and Jacobson and later standardised by the Object Management Group (OMG) in 1997. Since its introduction, UML has quickly become the standard modelling language for software development. Many users of other methods have adopted UML and most modelling tools have implemented support for the language [Eriksson and Penker 2000]. UML consist of nine different diagram types and each diagram shows a specific static or dynamic aspect of a system.

Despite the fact that UML is a standard modelling language for software development, it also can be used for business modelling, based on object-oriented concepts. A business model is shown from a number of views, each view being expressed in one or more diagrams. The diagrams can be of different types, dependent upon the specific structure or situation in the business, which is depicted. The diagrams capture the processes, rules, goals and objects in the business and their relationships and interactions with each other [Eriksson and Penker 2000].

2.3.1 UML basics

UML has nine predefined diagrams and each of them shows a specific static or dynamic aspect of a system. Therefore, two different types of business models of the system can be identified: static models, describing what the components of the system are, and behavioural models, showing how the system performs and reacts to external influence.

2.3.1.1 Static models

In general, the static aspect of a model can be represented by the static diagrams in UML, such as class diagrams, object diagrams, component diagrams and deployment diagrams, together with some constraints written in the Object Constraint Language (OCL). The definition of the static diagrams used in UML are given below according to [Eriksson and Penker 2000]:

- **Class diagram.** Describes the structure of a system. The structures are built from classes and relationships. The classes can represent or structure information, products, documents or organisations.

- **Object diagram.** Expresses possible object combinations of a specific class diagram. It is typically used to exemplify a class diagram.

- **Component diagram.** A special case of the class diagram used to describe components within a software system.

- **Deployment diagram.** A special case of the class diagram used to describe hardware within a software system.

2.3.1.2 Behavioural models

The UML dynamic diagrams such as statechart diagrams, activity diagrams, sequence diagrams, collaboration diagrams and use case diagrams can give the dynamic aspect of a model. The dynamic diagrams can be described as follows according to [Eriksson and Penker 2000]:

- **Statechart diagram.** Expresses possible states of a class (or a system).

- **Activity diagram.** Describes activities and actions taking place in a system.

- **Sequence diagram**. Shows one or several sequences of messages sent among a set of objects.

- **Collaboration diagram.** Describes a complete collaboration among a set of objects.

- **Use-case diagram.** Illustrates the relationships between use cases. Each use case, typically defined in plain text, describes a part of the total system functionality.

2.3.1.3 Eriksson-Penker business extensions

UML also provides three mechanisms for extending the approach to apply to the particular requirements of the modeller:

- **Stereotype**. An extension of the vocabulary of the UML, which allows the creation of new building blocks specific to a problem from existing blocks [Booch 1998]. Stereotypes may have their own icons.
- **Tagged value (property).** An extension of the properties of the UML element, which allows the creation of new information in that element's specification [Booch 1998].
- **Constraint.** An extension of the semantics of a UML element that enables new rules to be added or existing ones modified [Booch 1998].

The Eriksson-Penker Business Extensions use these three techniques to customise UML for real-life business modelling. They provide symbols for modelling the processes, resources, rules and goals of a business system.

The central concept of business modelling is the business process. In UML a business process has an explicit goal, a set of input objects and a set of output objects. The transformations, which the process makes on the input objects, can be physical, logical, transactional or informational. The UML tagged values attached to a process in the Eriksson-Penker Business Extensions are [Eriksson and Penker 2000]:

- **Goal.** A textual value that describes the goal of the process if a goal object is not explicitly attached to it.

- **Purpose.** A textual value that informally describes the purpose of the process; for example what the process does and, in the case of a new process, its anticipated effect.

- **Documentation.** A textual value that informally describes the work of the process; for example, the activities completed and the resources involved.

- **Process owner.** A textual value that defines the process owner, the person in the organisation who has the overall responsibility for this process and who manages the changes and plans for changes.

- **Process actors.** A textual value that defines the actors needed to run a process. Typically, their skill levels are described.

- **Priority.** A textual value that describes the priority of a process; for example, whether it's a core process, a support process, an administrative process and so on.

- **Risks.** A textual value that describes the risk of the process; for example, what can go wrong either when executing this process or when implementing this process in the business.

- **Possibilities.** A textual value that describes the potential of a process; for example, the opportunities for improving or using this process in the future.

- **Time.** A numerical value that approximates the execution time of the process.

- **Cost.** A numerical value that approximates the cost of executing the process.

2.3.1.4 Business events

A process is affected by events occurring in the surrounding environment or generated by other processes that cause a process to be activated. Business events are triggers that initiate activities or that control which activities are performed [Eriksson and Penker 2000]. Several events can occur during the operation of a process to which the process must react, such as cancellation of an order by a customer, a delivery of material, or the misplacement of specific resource. A process can also generate events to other processes within the business or in other businesses that will cause these other processes to react correspondingly. An event can:

- Initiate the execution of a process.
- Affect the behaviour and execution of a process.
- Conclude a process by generating an event.

In the Eriksson-Penker business notation a business event is represented as a class (the event type) and objects (instances of the event type). The event classes are stereotyped as a business event. The receive symbol (concave pentagon) and the send symbol (convex pentagon) are used in process diagrams to illustrate receiving and sending events. Either of the event symbols can be attached to an object with a dependency arrow, which shows from which object the event is sent or received.

2.3.1.5 Resources

Resources are the objects that act or are used in the business. They are the concepts consumed, produced, transformed or used by the business processes. Examples include material, energy, products, people, information and services. [Vernadat 1996] proposes a definition of the resource: "A resource is an entity which can play a role in the realisation of a certain class of tasks". Resource types are represented as classes. Resource instances are represented as objects. The Eriksson-Penker Business Extensions define the following stereotypes to indicate different categories of resource types [Eriksson and Penker 2000]:

- **Physical** – an entity with material reality that occupies a volume of space. It is something that can be seen and touched. Commodities, raw materials, parts or products are examples of physical resources.

- **Abstract** – an idea or concept, often a composite of other objects (e.g. a purchase order is a concept relating to a collection of things). Involves things and concepts that are not physical and cannot be touched but are of importance to the business. Contracts, roles, accounts and energy are examples of abstract resources.

- **Information object** – a representation of a concept, thing or another information object. It holds information about the resources and works as a surrogate for the resource, for example, in an information system. An information object can hold information about a bank account, a product or a contract.

- **People** – a human being acting in the process. It is a specialisation to the physical resource to emphasise and identify the people in the process.

2.3.2 Stereotypes and constraints according to Eriksson-Penker Business Extensions

The Eriksson-Penker Business Extensions provide a set of business model elements called stereotypes that allow the developers to model and capture the essence of a business. The stereotypes are divided into four categories: process, resource and rules, goals and miscellaneous. The stereotypes presented here are those adopted by [Eriksson and Penker 2000]. Table 2.2 itemises the process extensions and Table 2.3 lists the resources and rules extensions.

2.3.3 Business patterns

Patterns are established generalised solutions that solve problems that are common to different business solutions [Eriksson and Penker 2000]. They can be reused repeatedly and can be combined and adapted in many different ways. Patterns are not invented, but are found in existing models that describe real-life business systems.

Patterns found in business models are referred to as business patterns. Business patterns address problems within the business domain, typically analysis situations such as how to model and structure business resources that include invoices, organisation, information and so on. Business patterns also address how to organise and relate business processes, business rules, corporate visions and goals.

The business patterns presented by [Eriksson and Penker 2000] have the following categorisation suited for business modelling: Resource and rule patterns, Goal patterns and Process patterns. The resource and rule patterns are structural. They are combined in one category because rules are not easily separated from that they constrain or affect.

Goal patterns are also structural, while process patterns are both functional and behavioural.

2.3.4 Process patterns

Process patterns are behavioural and functional patterns whose intent is to increase the quality in workflow models and other process-oriented models. Process models normally refer to resources and are restricted by rules in order to satisfy the process goals. Therefore, the processes are descriptions of how to achieve specified goals with a set of predefined resources and rules, where the rules express possible states of the resource and the goals express desired resource states.

[Eriksson and Penker 2000] address three types of process patterns, each of which focuses on different aspects of process modelling. The first type consists of the Process Modelling patterns including the following: Basic Process Structure, Process Interaction, Process Feedback, Time-To-Customer, Process Layer Supply, Process Layer Control and Action Workflow Pattern.

The second process pattern type comprises the Process Instance patterns, which address the differences between the business process descriptions and the execution of those descriptions.

Process Support patterns make up the last type of process patterns. These patterns describe common problems and solutions inherent to business process deployment, which are normally implemented in some sort of application system that supports the business process. Such patterns are Resource Use and Process Instance State.

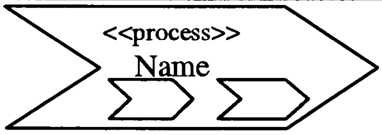
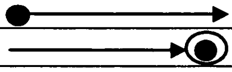
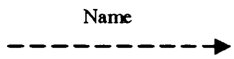
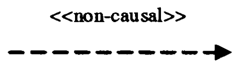
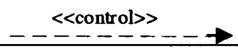
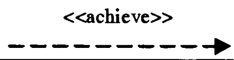
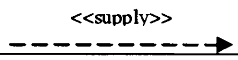
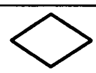
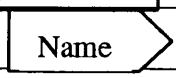
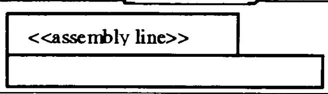
Name	Stereotyped to	Symbol	Definition/ Description
Process	Activity		A process is a description of a set of related activities that, when correctly performed will satisfy an explicit goal
Activity (atomic process)	Activity		A process might be divided into further processes. If these processes are atomic, they are called activities.
Process start	Start		Starts a process
Process end	End		Ends a process
Object-to-Assembly Line	Object		A delivered object from a process to the assembly line
Object-from-Assembly Line	Object		An object that goes from the assembly line to a process
Process flow	Control flow		A process control flow with a condition
Resource flow	Object flow		Object flow shows that an object is produced by one process and consumed by another process
Non-causal resource flow	Object flow		Non-causal object flow shows that an object might be produced by one process and consumed by another process
Process control	Object flow		Shows that a process is controlled by an object
Goal connection	Dependency		Allocates a goal to a process
Process supply	Object flow		Shows that a process is supplied by an object
Process decision	Decision		Decision point between two or more processes
Fork and Join of processes	Fork and Join		Forks and joins processes
Receive business event	Signal Receipt		Shows a receive business event
Send business event	Signal Sent		Shows a sent business event
Assembly line	Package		The assembly lines synchronise and supply processes in terms of objects

Table 2.2 - Process extensions

Name	Stereotyped to	Symbol	Definition/ Description
Information	Class	<<information>>	Information is a kind of resource. It is the knowledge increment brought about by a receiving action in a message transfer
Resource	Class	<<resource>> Name	Resources can be produced, consumed, used or refined in processes. Resources are either information or things. Things can be abstract or physical.
Abstract resource	Class	<<abstract>> Name	An abstract resource is an intangible asset, for example, mathematics, concepts and so on.
People	Class	<<people>> Name	A physical resource, specifically, human beings.
Physical resource	Class	<<physical>> Name	A physical resource, excluding people. For example, machines, documents and so on.
Business event	Signal	<<business event>> Name	A significant occurrence in time or space. A business event is one that impacts the business.
Business rule	Note	<<business rule>> Rule statement	Rules restrict, derive and establish conditions of existence. Business rules are used to specify state of affairs, including allowed business object states.

Table 2.3 - Resources and rules extensions

2.3.5 Discussion

In this section another contemporary process modelling technique was reviewed. After careful observation the following drawbacks of the UML have been identified:

- Since UML was defined to model the architecture of software systems, it is not completely suitable for business process modelling due to the differences between these two domains. To address this issue a set of extensions based on the existing model elements of UML is created, called Eriksson-Penker Business Extensions, however these are not yet sufficient to overcome the problem.
- The UML consists of nine different types of diagrams and each diagram shows a specific static or dynamic aspect of a system but there is no particular process model, which represents the whole picture of the system.
- Important information concerning the business processes and their execution is not placed in the UML diagrams. Information about the triggering and the terminating events of the process can be found only partially in the statechart and activity diagrams. There is no information about the organisational units involved in the process, neither for the documents supplying it, except for the process diagram, which belong to the Eriksson-Penker Business Extensions.
- The UML standardises notation for describing a process, but it does not standardise a methodology for producing those descriptions.

Therefore further work has to be devoted to extend UML in the direction of business process modelling to meet the needs of the business domain.

2.4 Case Based Reasoning (CBR) techniques

2.4.1 Definition of Case Based Reasoning - the CBR cycle

"A case-based reasoner solves new problems by adapting solutions that were used to solve old problems." – [Riesbeck and Schank 1989]

CBR is described as a cyclical process comprising the four **Re**s [Watson 1997]:

1. **Re**trieve the most similar case(s).
2. **Re**use the case(s) to attempt to solve the problem.
3. **Re**vise the proposed solution if necessary.
4. **Re**tain the new solution as a part of a new case.

A new problem is matched against the cases in the case-base, and one or more similar cases are retrieved. A solution suggested by the matching cases is then reused and tested for success. Unless the retrieved case is a close match, the solution will probably have to be revised, producing a new case that can be retained [Fig. 2.6].

This cycle rarely occurs without human intervention. For example, many CBR tools act primarily as case retrieval and reuse systems, case revision (or adaptation) often being undertaken by users of the case-base.

CBR is implemented computationally where each stage of the CBR-cycle is supported. The most important CBR components are described in detail as follows:

- **Case representation**

A case is contextualised piece of knowledge representing an experience. It contains the past lesson that is the content of the case and the context in which the lesson can be used. A case can be an account of an event, a story, or some record typically comprising:

1. The problem that describes the state of the world when the case occurred.

2. The solution that states the derived solution to that problem.

Within a case most types of data can be stored in a conventional database, such as names, product identifiers, values like cost or temperature and textual notes. An increasing number of CBR tools also support multimedia features, such as photographs, sound and video.

- **Indexing**

Most database systems use indexes to speed up the retrieval of data. An index is a computational data structure that can be held in memory and searched very quickly. This means the computer does not have to search each record stored on disk, which would be much slower. CBR also uses indexes to speed up retrieval. Information within a case is of two types: indexed information that is used for retrieval or unindexed information that may provide contextual information of value to a user but is not used directly in retrieval.

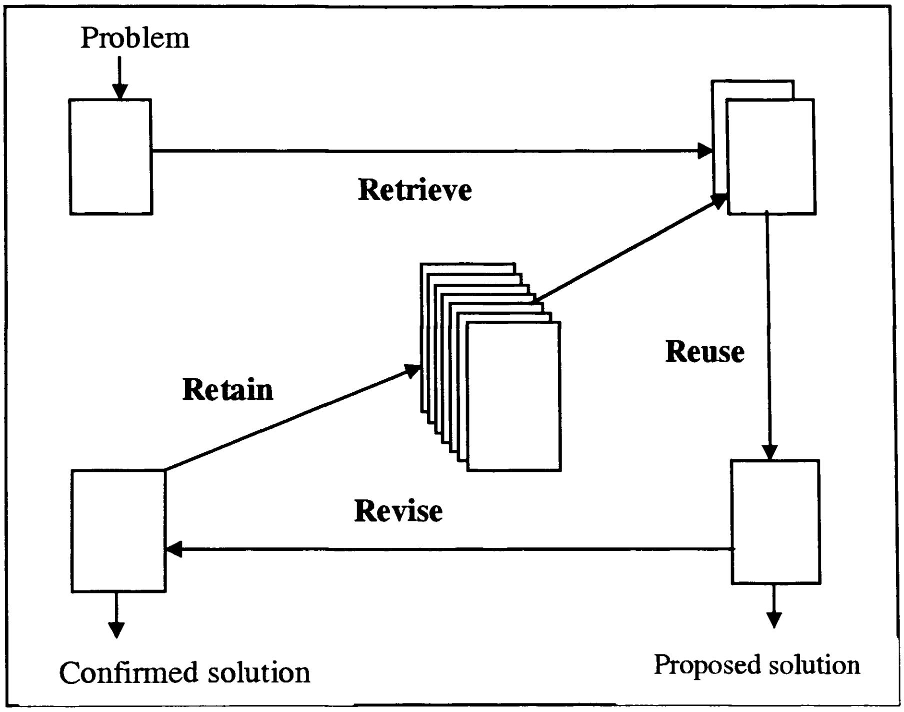


Fig. 2.6 - The CBR cycle

- **Storage**

Case storage is an important aspect in designing efficient CBR systems in that it should reflect the conceptual view of what is represented in the case and take into account the indexes that characterise the case. The case-base should be organized into a manageable structure that supports efficient search and retrieval methods. These methods are usually referred to as case-memory models. The two most influential academic case-memory models are the dynamic-memory model of Schank and Kolodner [Kolodner 1983] and the category-exemplar model of [Porter and Bareiss 1986].

- **Retrieval**

The retrieval of cases is closely related to and dependent on the indexing method used. In general, two techniques are currently used by commercial CBR tools: nearest-neighbor retrieval and inductive retrieval [Watson 1997].

- **Adaptation**

Once a matching case is retrieved, a CBR system will attempt to reuse the solution suggested by the retrieved case. In many circumstances the solution may be sufficient. However, in other instances the solution from the retrieved case may be close to the required solution, but not close enough. The CBR system must then adapt the solution stored in the retrieved case to the needs of the current case. Adaptation looks for prominent differences between the retrieved case and the current case and then applies formulas or rules that take those differences into account when suggesting a final solution. In general, there are two kind of adaptation in CBR:

- Structural adaptation applies adaptation rules or formulas directly to the solution stored in cases.
- Derivational adaptation reuses the rules or formulas that generated the original solution to produce a new solution to the current problem. In this method, the planning sequence that constructed the original solution is stored as an additional attribute of the case. Derivational adaptation can only be used for domains that are well understood.

2.4.2 Applications of case based reasoning

The classification of CBR applications used here has been adapted from [Watson 1997] and is laid out in [Fig. 2.7]. Being able to classify one's problem into a certain category of problem types is useful in helping to decide if CBR is appropriate and what type of CBR system may be required. CBR applications can be broadly classified into two main problem types - Classification tasks and Synthesis tasks.

Classification tasks cover a wide range of applications that all share certain features in common. A new case is matched against those in the case-base to determine what type or class of case it is. The solution from the best matching case in the class is then reused. Most commercially available CBR tools support classification tasks well and are primarily concerned with case retrieval. Classification tasks come in a wide variety of forms, such as:

- Diagnosis – for example, medical diagnosis or equipment failure diagnosis;
- Prediction - for example, the forecasting of equipment failure or stock market performance;
- Assessment - for example, risk analysis for banking or insurance or the estimation of project costs;
- Process control - for example, the control of manufacturing equipment;
- Planning – for example, the reuse of travel plans or work schedules.

Synthesis tasks attempt to create a new solution by combining parts of previous solutions. Synthesis tasks are inherently complex because of the constraints between elements used during synthesis. CBR systems that perform synthesis tasks must make use of adaptation and are usually hybrid systems combining CBR with other techniques. There are fewer of these systems but they involve such tasks as:

- Design – the creation of a new artifact by adapting elements of previous ones;
- Planning - the creation of a new plans from elements of an old ones;
- Configuration - the creation of new schedules from old schedules.

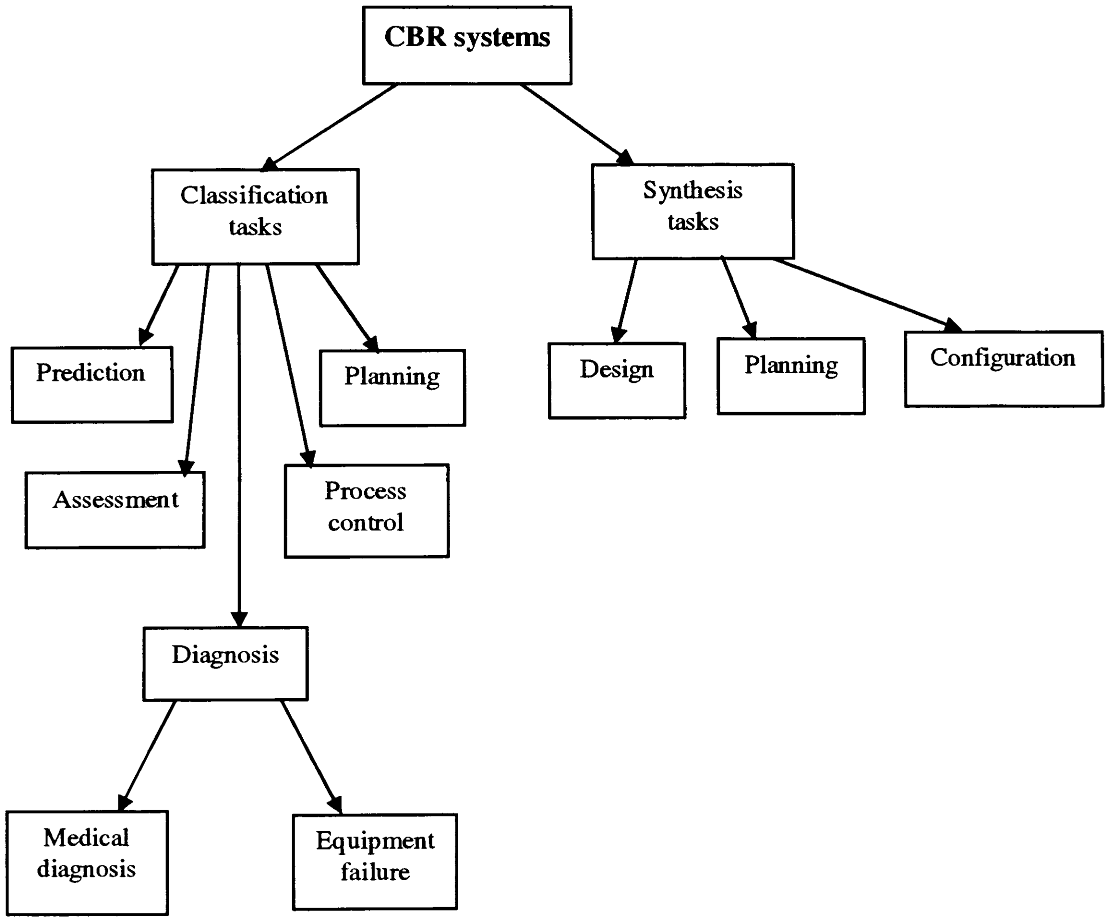


Fig. 2.7 - A classification hierarchy of CBR applications

2.4.3 Building and testing a case base

Applications using CBR will very rarely be built by simply taking an existing database of records and importing them into a CBR tool. Obtaining cases and defining their relevant features is a task akin to conventional knowledge engineering. Therefore a good case base should contain a representative and well-distributed set of cases to comprise a robust case library.

When acquiring cases it is important that they are representative of the problem domain. The developers of a CBR system must determine what features the cases should have and which cases should be acquired.

According to [Watson 1997] case bases in general divide into two categories:

1. Homogeneous case bases, where all cases share the same record structure – that is, cases have the same attributes but varying values.
2. Heterogeneous case bases, where cases have varied record structures – that is, cases may have different attributes and varying values

Another problem in building the case base is how to acquire representative cases. This relates to the completeness problem in conventional knowledge engineering. It has been reported that CBR systems have a significant advantage over rule-based systems in that they can be delivered with incomplete case bases. Usually the developers advise that case bases should be 80% complete before delivery.

Acquiring representative cases and case distribution are very closely linked. Case distribution refers to the coverage of cases across features. Usually a features shift is used for better case distribution. The feature shift demands that cases be clustered more closely around the point of feature shift, particularly if relatively simple structural adaptation techniques (such as interpolation) are used.

Testing or evaluating a CBR system involves two separate processes, called verification and validation. Verification is concerned with building the system correctly and Validation is about building the correct system.

2.4.4 Maintaining case bases

CBR systems can grow with the time, which is one of the major benefits of the technology – their ability to learn and to improve their performance by acquiring new cases. However, this learning process should not be left to chance. To leverage continuing improvements from the CBR system, it has to be maintained. This process is very closely linked to verification of the case base, since in some ways the development of a CBR system is never completed, it is an ongoing process.

2.4.5 Discussion

This section reviewed the concepts and technology of case-based reasoning. It has outlined the CBR cycle, together with some applications of case-based reasoning and how to build and test a case base. The problem domains suitable for case-based reasoning were also classified. In general, those problems, which can be considered as classification tasks, such as diagnosis and prediction, are easier to implement than tasks that require synthesis, such as design. CBR also provides a methodology for capturing new problem-solving experiences and easily acquires new cases, which ensures the success of the system after it becomes operational. The CBR methodology could be applied together with business process modelling techniques aiming to produce new process models based on the existing ones from the case base. This will lead to fast and easy creation of new process models together with business process reengineering of existing process models.

2.5 Enterprise web portals

2.5.1 Definition of Enterprise Portals

According to [Shilakes and Tylman 1998]: "Enterprise Information Portals are applications that enable companies to unlock internally and externally stored information and provide users a single gateway to personalised information needed to make informed business decisions. They are an amalgamation of software applications that consolidate, manage, analyse and distribute information across and outside of an enterprise (including Business Intelligence, Content Management, Data Warehouse & Mart and Data Management applications)".

2.5.2 Types of portals

Murray distinguishes four types of portals [Murray 1999]:

- **EIPs (Enterprise Information Portals)** provide people with access to information by structuring database content on particular subjects or themes;
- **Collaborative portals** enable teams of users to establish virtual project areas or communities. Such portals include tools for co-operative working within such communities;

- **Expertise portals** link people together based on their skills and expertise, as well as their information needs;
- **Knowledge portals** are aimed at the generation, acquisition, transmission and management of knowledge related to enterprise business processes, e.g. sales, marketing and risk management.

2.5.3 Services provided by portals

Classic Internet sites and marketplaces offer three types of services, all of which must be integrated into enterprise portals [SAP R/3 2000]:

- **Information services** including general news, industry or community specific news, stock information and weather;
- **End-to-end services** offer a complete package of dedicated services, such as travel management, shipping services and financial services;
- **Collaborative services**, such as chat rooms, blackboards and team rooms to facilitate a global community performance.

The range of services offered by an Enterprise Information Portal is shown in [Fig. 2.8] [OpenText 1999]. Some of the basic services provided by a portal are described, such as e-mail, discussion groups, subscription services, news, etc. Information concerning enterprise aspects is also included, such as ERP (Enterprise Resource Planning), enterprise resources, project information, corporate information and department documents.

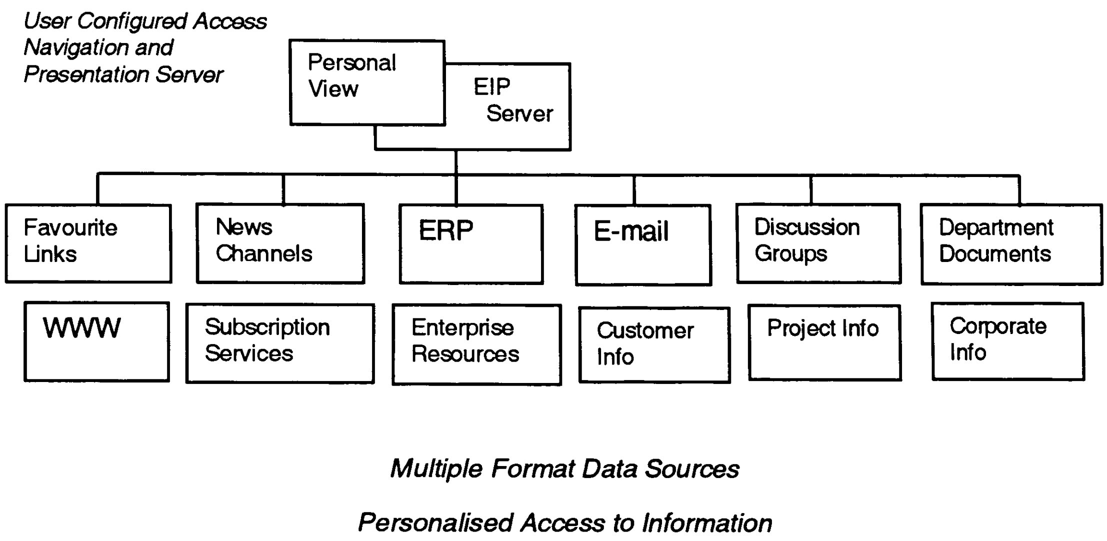


Fig. 2.8 - Enterprise Information Portal

2.5.4 State-of-the art of enterprise portals

The Internet has stretched business processes across the traditional organisational boundaries, so that several companies can work together on one business process. Examples of this include collaborative forecasting, vendor managed inventory, and distributor/reseller management, together with the traditional buying and selling applications. Enterprise portals should provide solutions for this higher level of user integration and enable efficient business process control.

Internet features must therefore be combined with enterprise information authoring and management systems, such as CAD, PDM, ERP, to create Enterprise Web Portals, with the mission of providing the right information to the right person at the right time and in the right format anywhere within the extended enterprise [Rezayat 2000b].

A survey of recent trends in Enterprise Web Portals reveals several important issues in the current economy: market globalisation, decentralisation and geographically dispersed project teams, complex IT infrastructure and information overload.

These issues highlight the need for a solution allowing the integration of disparate application systems, and knowledge and information sources.

The portal concept makes good sense at the corporate level, with many products now available for building corporate intranet-based portals. Corporate portals should provide all the usability and consolidation features of Web portals, but tuned to the unique requirements of a company's own employees and their collaborative business processes [Watson and Fenner 2000].

Most companies are looking for portals to provide two specific types of functionality:

- means for gathering information from disparate data sources and for making it available to users;
- common browser-based interface through which users can do whatever they need – searching, accessing documents, or interacting with other users, etc.

The portal concept represents one of the best options that companies have for providing a single window into the information, business processes, and tools that users require to do their jobs effectively. Portals also provide a compelling solution for the embodiment of knowledge management practices through a single user interface. For organisations, the challenge lies in determining how to put all the necessary technology pieces, data sources, and knowledge management services together for a solution that actually provides measurable value [Watson and Fenner 2000].

When using corporate portals, the benefit to the user is one-stop access to information, in context, provided from multiple sources and in common formats. The benefit to the IT department is consistency in the interface, centralised control over multiple sources of data and expanded use of information across the organisation.

At minimum, a corporate portal must provide at least three components. First, the portal requires a structure or methodology to support and organise the information content. Second, the portal requires an infrastructure to manage security and to control access to sets of internal and external information. Third, the corporate portal requires integrated tools to search across multiple repositories and display results that are relevant to the user's individualised requests. As the corporate portal grows in sophistication, the user is offered extended customised features, expanded options for how to display information and enhanced capabilities to fine tune what is being sent to them [OpenText 1999].

Corporate portals have the potential for providing organisations with rich and complex shared information workspace for the creation, exchange, retention and reuse of knowledge. To elaborate this position, [Detlor 2000] presents an information-based model of the corporate portal. The model consists of three major components of a portal's shared information workspace: a content space to facilitate information access and retrieval; a communication space to negotiate collective interpretations and shared meanings; and a co-ordination space to support co-operative work action. The provision of a shared information workspace may offer great benefit to organisations in helping employees to acquire, distribute, interpret, store and retrieve information in their daily work practice.

The basic requirements for Enterprise Information Portals are speed and ease of deployment, flexibility, scalability, ability to integrate, reliability and security.

Collaborative portals provide a suitable environment for collaborative definition of business processes and a common workspace where the results of discussions between team members can be stored. In addition, access to object-oriented functionality within these portals allows new objects and patterns of objects to be created in an interactive mode.

Another useful tool for computer-aided collaborative problem solving is provided by the "blackboard" functionality of the portals. This has also been used to support computer-aided collaborative product development. [Huang and Mak 2001a] investigated the possibility of combining the concepts of agents, blackboards and workflows within a common workspace environment.

The Enterprise Web Portal can help the enterprise user connect to other users, to the Internet, to any database or computer on the network, and essentially to any electronic device with an IP address and information. It is not too difficult to imagine how the manufacturing industry will flourish in this paperless electronic world. Today, most detailed design and manufacturing is still performed using paper drawings and most, if not all inspection, validation, assembly, approvals, and procurements require paper and physical prototypes. These methods have been in practice for many years with de facto industry standards and understood limitations. However, what is even more troubling is that there is practically no collaboration involved; all parties live in virtual information vacuum until it is their turn to look at the data. In contrast, with an Enterprise Web Portal everyone can be involved simultaneously throughout the development cycle and the information is both shared and collaborated upon in a controlled environment [Rezayat 2000b].

To help realise the potential of portals as shared information workspaces, a new orientation may be required in corporate portal and intranet design. Typically organisations launch portal and Intranet development initiatives as a means to reduce internal information publishing costs and enhance corporate information distribution [Rice 1996; Thyfault 1996]. Portal design can be more ambitious than this by providing functionality which helps small and large groups of people co-operate and work together more efficiently [Small, 1999]. Tight integration with suppliers and customers throughout the entire product development cycle is also seen as essential.

Most of the claimed advantages of corporate portals centre on the business benefits provided by their user features. These benefits include improved customer service, innovation, faster time to market, and competitive advantage. However, a number of challenges still remain concerning portals: practical portal development, information integration, user-empowering interfaces, and knowledge management support [Watson and Fenner 2000].

Concerning enterprise integration, one of the major concerns in industry is the interoperation of the business processes. However efficient technical solutions remain to be provided for two basic scientific issues in order to achieve process interoperability:

semantic unification as the basis for information and knowledge sharing and process co-ordination in large distributed business environments.

2.5.5 Discussion

This section highlights the needs for a corporate portal in the contemporary business environment. A review of enterprise portals was conducted and the main features and services of the portal have been introduced. It is concluded that the provided collaboration services could be enriched, and that the enterprise resources should be better integrated into the portal structure. The workflow engine service provided by the portal also would be of great benefit for the enterprise; hence more effort should be dedicated to that direction. Finally, more applications should be integrated in the portal to provide a complete and flawless environment for the project team of the enterprise.

2.6 Summary

This chapter has focused on a review of business process modelling techniques, CBR and enterprise portals, that can be used to provide a distributed business environment for geographically dispersed partners. It is concluded that an ideal enterprise portal synthesises both decision and collaborative processing orientations, leaving room for novel syntheses of these two areas.

Combining computer-integrated manufacturing and business process modelling is another area for synthesis. The objectives for such a synthesised system may be to build an integrated and modular manufacturing system complying with user requirements, to verify the design of its business processes, to support the design and analysis of the necessary information systems, to select the functional entities to be installed (e.g. resources) and to predict system performance.

The idea behind developing enterprise integration modelling frameworks is that a large part of business process re-engineering projects are in fact similar and common to every type of business. Thus, they could be captured, standardised, and re-used instead of developing them again from scratch each time. Once standardised, generally accepted frameworks can be supported by models and methodologies, leading to time and cost efficiencies. Such standard models could be stored in a case-base and then reused in new situation by applying case-based modelling techniques. This chapter has provided an overview of CBR as a synthesis tool for creating and adapting business process models.

Chapter 3 - Business Process Models with Feedback

In Chapter 2, a review of conventional and advanced business process modelling techniques was conducted. One of the existing approaches for business process modelling is the Product/process methodology [Kaposi and Myers 2001]. Based on its fundamental principles and key concepts, several extensions to this methodology are developed to overcome some of its limitations. In this chapter the proposed improvements are discussed in detail together with a case study used to validate them. The performance of the proposed extensions to the P/p methodology is analysed and compared with that of the Unified Modelling Language (UML). Finally, conclusions are made about the suitability of these extensions for business process modelling and their advantages in comparison to UML.

3.1 Preliminaries

The review of Business Process Modelling techniques and Enterprise Collaborative Portals in Chapter 2 has identified two main problems:

1. Existing process modelling tools do not focus on resource management and tend to produce non-executable models [Vernadat 1996]. There is no efficient enterprise integration that addresses process co-ordination issues in large distributed business environments. A new methodology is therefore required for developing richer models, encompassing all aspects of enterprise modelling, including organisational aspects, resource management, product models and activity models;

2. There are no solutions available that address the process modelling and co-ordination issues of dynamic workflows and could support geographically dispersed teams. To

develop such solutions it is essential that all participants in a project contribute to the creation of such models. An environment enabling collaborative work between globally distributed corporate partners is required [Firestone 1999]. An Enterprise Collaborative Portal could provide such functionality.

The first problem can be successfully addressed by applying the Product/process (P/p) methodology, introduced in [Kaposi and Myers 2001]. This methodology suggests a new approach to process modelling, which incorporates product data. It offers a "systems world view", which is helpful to clients, suppliers and users of complex systems. The P/p graph is adopted as a means to represent the modelled process. This particular representation is appropriate for the following reasons:

- The P/p methodology associated with the P/p graph combines the systems concepts with those of traditional engineering disciplines, including rigorous models, measurements and quality management.
- A P/p graph is a representation, where products and processes are characterised by their attribute values. It is a simple, clear and logical tool for modelling systems, expressing the ideas of individuals, facilitating communication between interested parties, analysing, designing and developing systems, and reasoning about them.
- The P/p graph can help identifying entities that need describing or whose attributes need defining and measuring.

After a careful study of the P/p methodology two main limitations were encountered:

1. The time duration of the product is assumed to be zero, which is not true in practice. Products should be modelled according to the requirements of the real time. Therefore,

different time stamps should be assigned to them, since their attribute measures undergo changes at different time instances;

2. There are no feedback operators in P/p graphs – the modelling tool of the P/p methodology. As currently formulated the P/p graph must be free of feedback because it would imply the simultaneous presence in the process input of two products with different time stamps. Therefore, a proper formalism for representing feedbacks has to be incorporated in P/p models so they can represent the real behaviour of the business process. The P/p methodology can accommodate feedbacks of the kind used in continuous systems, which is a suitable shorthand representation of repeated single-shot processes in discrete systems.

To overcome these limitations several extensions to the P/p methodology are proposed that incorporate feedback into the model of the process and provide a proper formalism for representing it. When such feedback is introduced in the model, the same product may have two (or more) different time stamps, which could be represented by a set of time stamps. Thus, a product will have time duration, similar to that of the respective process. Therefore, in the proposed extensions a cyclic graph is used, where time stamps are assigned accordingly.

3.2 Product/process model with feedback

3.2.1 Incorporating a feedback into the process model and its influence on the time stamps and the process duration

The approach that is employed to incorporate feedback in the P/p model is based on the control theory. The key components of any control model according to [Nise 2000] are presented in [Fig. 3.1].

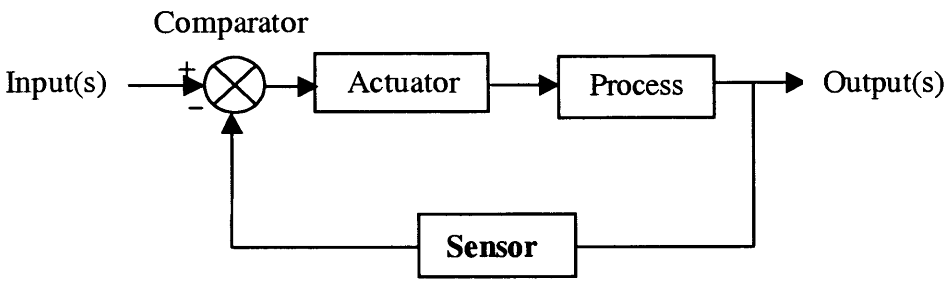


Fig. 3.1 - The key components of control models

Consider a simple single-input and single-output process **p** in [Fig. 3.2], where P_1 is the input product with time stamp t_1, P_2 is the output product with time stamp t_2 and the feedback is represented as  (the sensor).

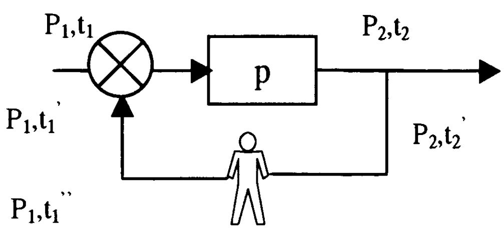


Fig. 3.2 - A simple process with single input, single output and feedback

It is obvious that P_2 is the input product for the feedback and P_1 is the output product. Actually P_1 is the same product but with different time stamps: t_1', t_1'' etc. after each new feedback iteration. Thus, the product does not have only one time stamp as in the P/p methodology. It will have a set of time stamps. In this way, the product P_1 should have time duration, which is the sum of the durations of the process **p** and the feedback process. If a few iterations are required, then a coefficient **k** is used to indicate how many times a feedback was applied.

Since the duration of process **p** is $\partial t_p = t_2 - t_1$ for the first iteration (in this case **k**=1) and the duration of the feedback process is $\partial t_f = t_1' - t_2$, thus the duration of the product will be $\partial t = \partial t_p + \partial t_f$ or $\partial t = t_1' - t_1$. If there is a need for a second iteration (**k**=2) the process **p** will have time duration $\partial t_p = t_2' - t_1'$ and the duration of the feedback will be $\partial t_f = t_1'' - t_2'$, whereas the duration of the product P_1 will be $\partial t = \partial t_p + \partial t_f$ or $\partial t = t_1'' - t_1'$. It could be concluded that for the k^{th} iteration, the product duration would be

$$\partial t = t_1^{k+1} - t_1^{k} \tag{3.1}$$

Finally, the whole duration of product P_1 will be sum of all durations ∂t for the different iterations:

$$\partial t = \sum_{k=1}^{n} \partial t_k = \sum_{k=1}^{n} (t_1^{k+1} - t_1^{k}) \tag{3.2}$$

where **n** is the number of iterations, ∂t_k is the duration of the product during the k^{th} iteration.

The following conclusions could be made:

- The product will have a set of time stamps in order to compute its duration;

- The feedback itself is also a process, i.e. it is a black box system. Therefore, it is better to present the feedback as feedback system F in the P/p graph;
- A formal representation of the feedback process as a black box has to be provided.

3.2.2 Definitions of the main concepts

The definitions of time, time stamp and time duration used in this research are the same as in [Kaposi and Myers 2001]. The distinction between a product and a process according to P/p methodology relates to the measure of time duration, "product" being instantaneous (having zero duration) and "process" having finite non-zero duration. Thus, as it was already discussed in the previous section the same product would have different time stamps for each iteration when feedback is incorporated into the P/p model. In this case the product will have time duration, similar to that of the respective process, which can be calculated by a formula that takes into account the set of time stamps of a given product. Therefore, a new definition of product has to be introduced.

3.2.2.1 Product

Based on the product definition suggested by [Kaposi and Myers 2001], in the proposed extensions a product is defined as a representation of a passive referent by an attribute set. Such set contains a time set and an interrelation set. The time set consists of a set of time stamps and time duration attributes. The interrelation set includes a measure of the time instant at which all attributes are valid, and the interrelation between the attributes characterising this referent.

Incorporating feedback into the P/p model also affects the process definition since it is linked to the modified definition of the product. Therefore, the process definition should undergo changes to reflect this. New attributes characterising the process have to be introduced to specify whether it has a feedback or not and also to record the number of iterations associated with such feedback. These attributes are called "feedback parameters" and provide information about feedback status – showing whether the process has a feedback or not, the number of feedback iterations, actuator, sensor and comparator.

3.2.2.2 Process

Based on [Kaposi and Myers 2001] a new process definition is suggested. The process is a representation of an active referent that is formally defined as a set of interrelated attributes, transforming an input product into an output product over a period of time.

The attributes characterising a process include:

- A duration: the time period of the operation, given as a constant or as a variable;
- The domain of valid input products;
- A transfer function: a function which evaluates the attributes of the input product to derive the attributes of the output product;
- A status: whether the feedback process is active or not (open for business or not) at the time of arrival of the input product;
- A designation of the process owner;
- A cost: the cost incurred by executing the process, if the process is man-made;
- Feedback parameters, which provide information about:

- feedback status – binary attribute ("yes" or "no") indicating whether the process has a feedback or not;
- n, representing the number of feedback iterations in case the feedback is present, otherwise n=0;

In addition, this set includes two other mandatory attributes:

- Data about the attributes' interrelation: the assertion that all attributes characterise the same process;
- A time set: a set of real time instances at which the input product is generated by the feedback in case such exists for the particular process and the time duration of the input product.

In some cases other process attributes might be specified, for example the means by which the process is executed, for example by employing an agent.

3.2.2.3 Feedback

The feedback is an inverse process related to another process and is a representation of an active referent. The attributes characterising a feedback process are similar to those associated with a process, such as: duration, the domain of valid input products, transfer function, status, cost and **n** - the number of feedback iterations. In addition, it includes attributes defining actuator, sensor and comparator, and the same mandatory attributes associated with any process: data about attributes' interrelation and a time set.

3.3 Formal description of a business process model with feedback

3.3.1 Product formal representation

The formal representation of a product is based on the black box representation introduced by [Kaposi and Myers 2001] (see Appendix A.1). Several extensions are added to it to reflect the new product definition. These extensions are defined based on a finite set of attribute measures E_{BP} that characterise process **p** as a black box. The time set TS_{BP} used in these attribute measures E_{BP}, is defined as follows:

$$TS_{BP} = \{T_{BP}, \partial t\} = \{\{t_B^1, t_B^2, ..., t_B^n\}, \partial t\}, \text{ where}$$

- **n** is the number of feedback iterations.
- $T_{BP} = \{t_B^1, t_B^2, ..., t_B^n\}$ - a finite set of the different time stamps of the product P_B, when feedback is incorporated. If the product is not involved in a feedback process, then this set will have only one element.
- ∂t - time duration of the product, which is calculated base on the time stamps of the product:

$$\partial t = \sum_{k=1}^{n} \partial t_k = \sum_{k=1}^{n} (t_B^{k+1} - t_B^k), \tag{3.3}$$

  where t_B^k is the time stamp of the product during the k^{th} iteration.

In case there is no feedback, the time duration of the product will be zero.

3.3.2 Process formal representation

Similarly, the formal representation of a process is based on the black box representation of [Kaposi and Myers 2001] (see Appendix A.2). The new process definition requires this representation to be broadened. In particular, a feedback parameter FP is added to the finite set of attribute measures E_{BP}, that is defined employing the following attributes:

$$FP=\{FS, n\}, \text{ where}$$

- FS - feedback status – Boolean parameter, showing whether the process has a feedback or not;
- n, integer number representing the feedback iterations in case feedback is present, otherwise n=0;

Also changes are introduced into the finite set of relations R_{BP} over E_{BP}. Instead of the time stamp t, the time set TS_{BP} is used.

3.3.3 Feedback formal representation

As discussed in Section 3.2.2.3 a feedback is an inverse process related to another process. Therefore, the formal representation of a feedback is similar to that of a process (see Appendix A.3) and includes only additional attributes related to the finite set of attribute measures E_{BP}:

- n – integer number, representing the number of feedback iterations,

  A – string parameter, representing the actuator,
- S - string parameter, representing the sensor,
- $\otimes$ - string parameter, representing the comparator.

The finite set of relations over E_{BP}, R_{BP}, is the same as that defined in the formal representation of a process.

3.4 Model representation using the extended Product/process graph

The capabilities of the proposed approach are demonstrated on a task involving the development of a simple product, a golf training device, assembled from four parts: body, pulley, pulley vee block and squaring bar. The task is to build a prototype of this device employing the Rapid Prototyping technology.

To simplify the task only one subprocess of the main business process is considered that deals with the customer requirements and the negotiations on corresponding quotation for the job. Initially, a Process Chain Diagram (PCD) of the Preparation and Negotiation (P&N) subprocess is created as shown in [Fig. 3.3]. Then the P/p graph and its supporting tables are defined by applying the P/p methodology that provide more detailed information about the business process. The P/p graph of P&N subprocess is given in [Fig. 3.4]. For clarity, the corresponding products and processes to the events and activities/actions in the P/p graph and the PCD respectively are given in [Fig. 3.3]. All products and processes of the P/p graph are described in [Table A.1] and [Table A.2] in Appendix A.4. [Tables A.3 and A.4] in the same Appendix present product $\mathbf{P_1}$ and process $\mathbf{p_1}$ with their attributes, respectively. To define fully the model of this subprocess, the tables of all its products and processes, similar to [Table A.3 and A.4] should be defined.

There are several unsolved issues arising when applying [Kaposi and Myers 2001] P/p methodology:

1. Where can the information about the triggering and the terminating events be stored in the P/p graph? In this research to address this problem it is proposed the events to be considered as products. In particular, the events, which are triggered by actions using AND, OR, XOR or other operators, can be presented by collection and distribution gates.

2. How can the organisational units be represented in the P/p graph? To address this issue it is suggested organisational units to be considered as process attributes, such as "a designation of a process owner". Thus, an organisational unit is equivalent to a process owner.

3. Where can information about the documents related to a certain process be found?

To answer this question a number of possible solutions were considered. First, the documents were regarded as products but this increases significantly the complexity of the P/p graph. Then the possibility to consider the documents as process attributes was studied. This led to simplification of the P/p graph and made it easier to comprehend. Thus, it was decided the information about the documents to be stored in the Tables of Processes, as additional process attributes. In case a process does not have supporting documents the fields for these attributes are left blank.

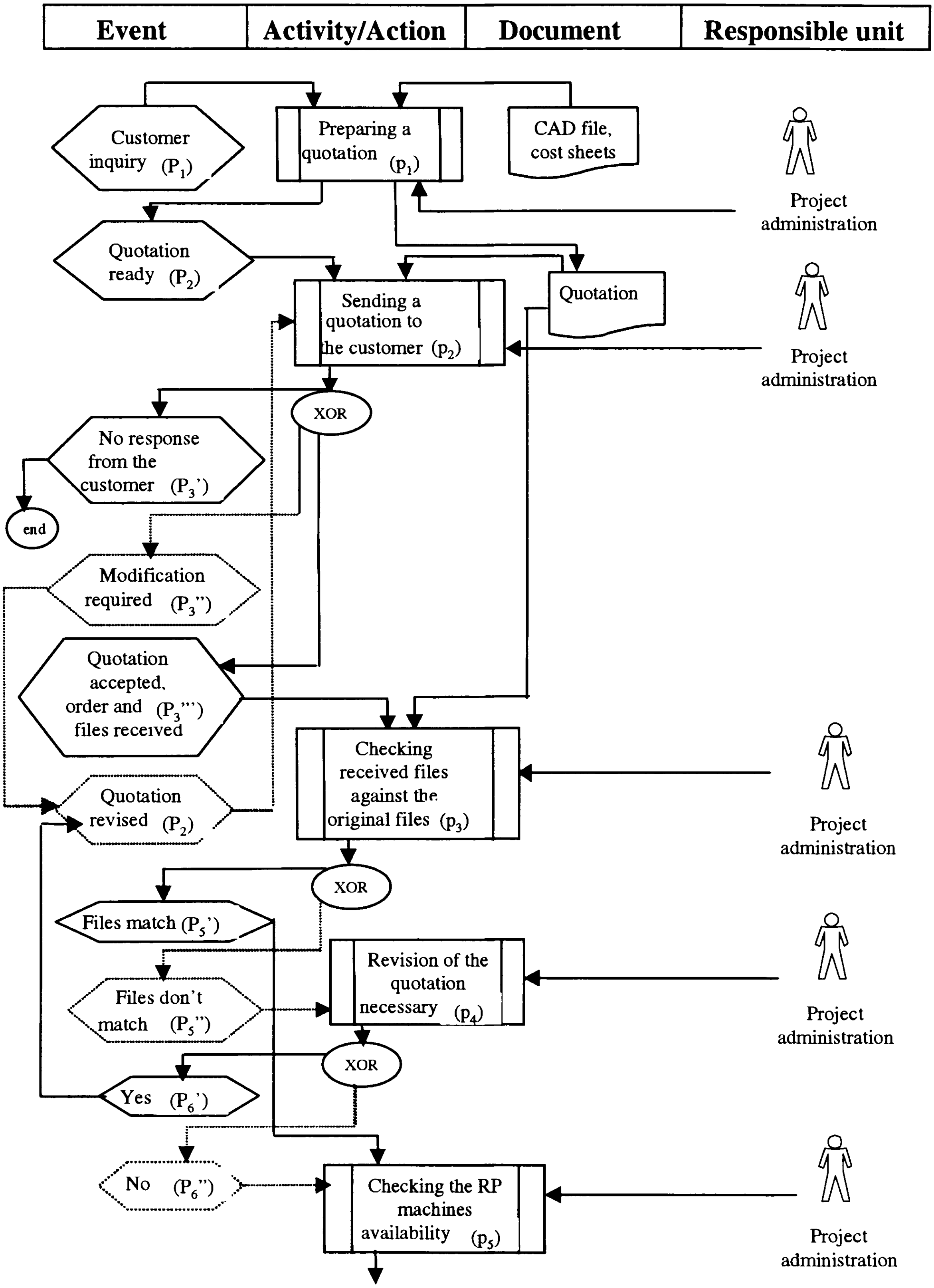


Fig. 3.3 - Process chain diagram of the Preparation and Negotiation subprocesses

Note: The corresponding processes and products to events and activities/actions in the P/p graph and the PCD respectively are given in the brackets.

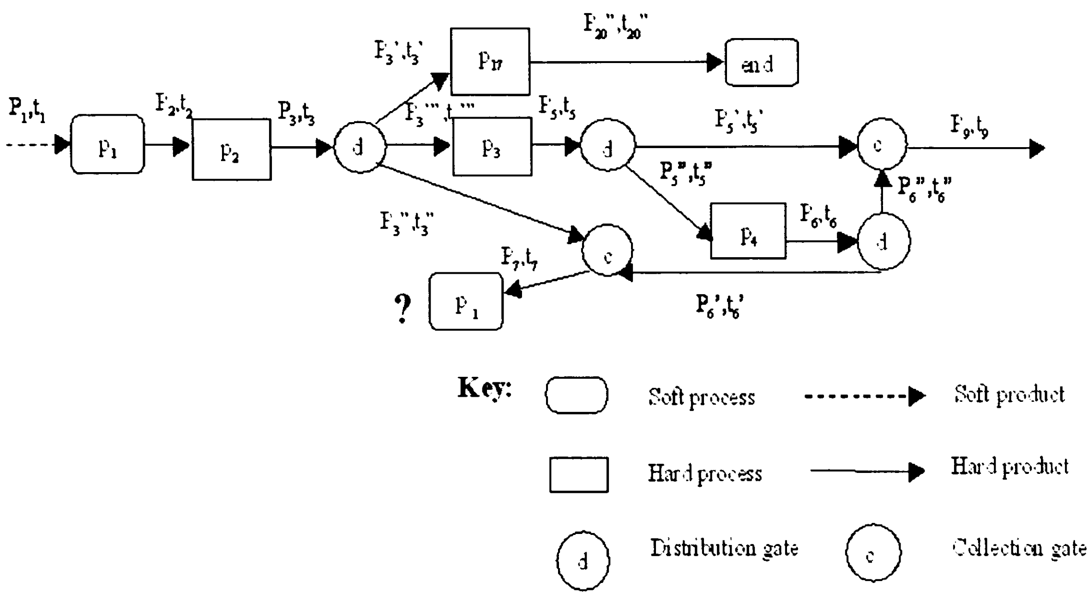


Fig. 3.4 - P/p graph of the Preparation and Negotiation subprocesses

As discussed, one of the limitations of the P/p methodology is the lack of feedback. The P/p graph in [Fig.3.4] that is designed according to the P/p methodology cannot represent the feedbacks from the customer during the P&N subprocess. Both products P_1 (Customer inquiry) and P_7 (Requirements for revision) are inputs to the same process p_1 (Prepare/revise quotation), which cannot be represented on the graph due to existing constraints in the P/p methodology. To illustrate the advantages of the proposed extensions to the P/p methodology, this P/p graph is revised in [Fig. 3.5] by implementing the feedback principles described in Section 3.2. The feedback is represented on the graph as system F_1, which has to be "tuned" by the sensor (the customer) and the comparator (the project administrator) to reflect correctly the customer requirements. The input for this system is product P_1 (Customer inquiry) and the output is product P_3''' (Quotation accepted, order and files received) and its goal is to achieve a better match between the customer requirements and the offered service. Different pricing structures, product quality and delivery times could be considered as actuators. There are two new products added to the graph, P_{25} (Customer response analysed) and P_4 (Customer requirements).

The products, processes and feedbacks in Fig. [3.5] are presented in Table 3.1, Table 3.2 and Table 3.3.

Product	Description	Collection (c) or distribution (d) gate	Class of product	Graphical symbol
P_1	Customer inquiry		soft	- - - -→
P_2	Quotation ready/revised		hard	⟶
P_3	Customer response received	$d(P_3', P_3'', P_3''')$	hard	⟶
P_3'	No response from the customer		hard	⟶
P_3''	Modification requirements		hard	⟶
P_3'''	Quotation accepted, order and files received		hard	⟶
P_4	Customer requirements		hard	⟶
P_5	Files checked	$d(P_5', P_5'')$	hard	⟶
P_5'	Files match		hard	⟶
P_5''	Files don't match		hard	⟶
P_6	Revise the quotation?	$d(P_6', P_6'')$	hard	⟶
P_6'	Yes		hard	⟶
P_6''	No		hard	⟶
P_7	Requirements for revision	$c(P_3'', P_6')$	hard	⟶
P_9	Check the machines	$c(P_5', P_6'')$	hard	⟶
P_{20}''	No order		hard	⟶
P_{25}	Customer response analysed		hard	⟶

Table 3.1 - Products in the extended P/p graph of the Main Business Process

Feedback	Description	Input	Output	Comparator	Actuator	Sensor	Goal
F_1	Customer feedback for the quotation	P_1	P_3'''	Project administrator	Price, quality, time	Customer	To address customer requirements

Table 3.2 - Feedbacks in the extended P/p graph

Process	Description	Owner	Input product	Output product	Document	Class of process	Graphical symbol
p_1	Prepare/revise a quotation	Project administration	P_1	P_2	CAD file, cost sheets	soft	
p_2	Send a quotation to the customer	Project administration	P_8	P_3	Quotation	hard	
p_3	Check the received files against the original files	Project administration	P_3'''	P_5	Quotation	hard	
p_4	Check if revision of the quotation is necessary	Project administration	P_7	P_6	-	hard	
p_{17}	No order	Project administration	P_3'	P_{20}''	-	hard	

Table 3.3 - Processes in the extended P/p graph of the Main Business Process

The supporting information about products and processes according to the introduced new definitions is given in [Tables A.5 to A.9] in the Appendix A.4. [Table A.7] and [Table A.8] represent a particular product and process with their attributes according to extensions in the P/p methodology. [Table A.9] shows an example of a feedback definition, in particular the definition of feedback F_1.

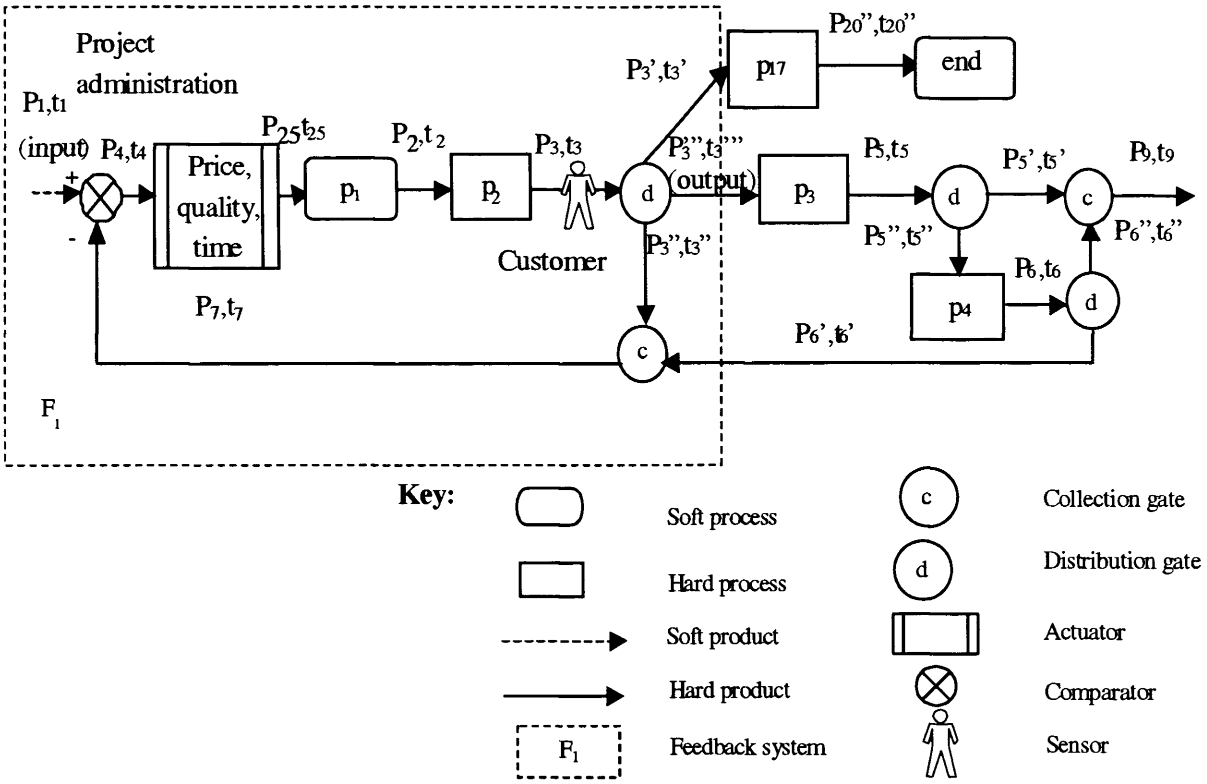


Fig. 3.5 - Revised P/p graph of the subprocess incorporating feedback

3.5 Comparison between the extended Product/process model and the UML model

To demonstrate the advantages of the proposed extensions to the P/p methodology their modelling capabilities are contrasted with those of the Unified Modelling Language (UML). To carry out this comparison UML is applied on the same case study, the development of a golf training device, used to demonstrate the capabilities of the proposed modelling approach in this research.

The Eriksson-Penker Business Extensions [Eriksson and Penker 2000] represent a process in a UML class diagram by applying the process symbol described in the Appendix B. The key used in all UML diagrams presented in this section is common for Eriksson-Penker Business Extensions discussed in Chapter 2.

For the purpose of this study the process diagram has been chosen as the most suitable tool to represent the business processes together with their resources, input and output objects and organisational units. A process diagram of the main business process containing the Preparation and negotiation subprocess described in Section 3.4 is shown in [Fig. 3.6]. The input objects of the main business process are "Customer inquiry", which is an abstract object and "CAD file and cost sheets" being documents, i.e. physical resources. There is one output object – "Prototype", which is also a physical object. The supplying resources are represented by "Materials and SLS machine", which are physical resources and "RP project manager" from the resource type <<people>>. The process is controlled by "Project administration", which is a <<people>> type resource and the goal of the process is to satisfy customer requirements, a qualitative goal. The main business process itself consists of four subprocesses: Preparation, Negotiation, Accomplishment and Acceptance, as shown in [Fig. 3.6].

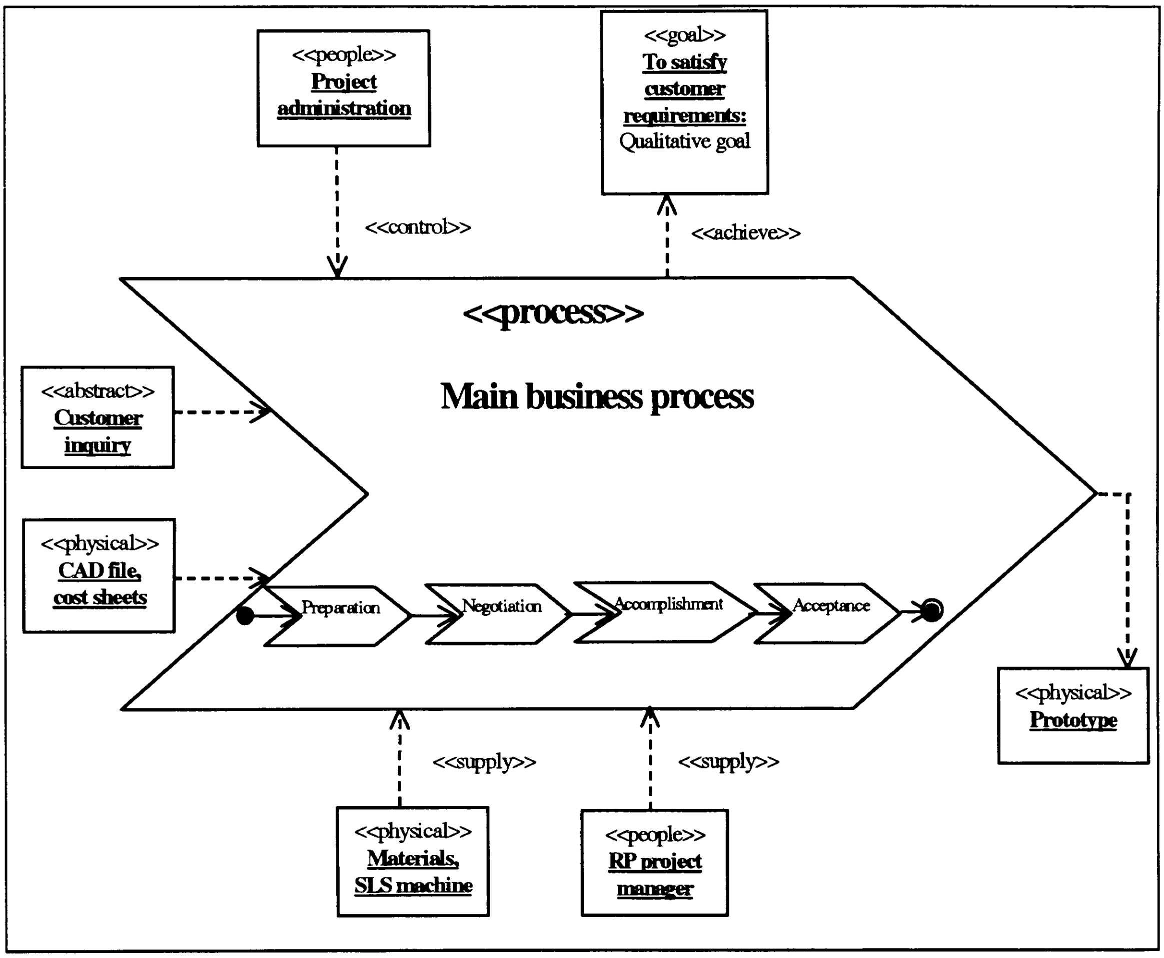


Fig. 3.6 - Process Diagram of the Main Business Process

Compare the UML diagram of the Main business process in [Fig. 3.6] with the extended P/p graph in [Fig. 3.5]. The process diagram gives only the "big picture" of the process, without its activities and events. In contrast, the extended P/p graph presents the process in detail. Both representations provide techniques to visualise subprocesses. The main business process in the UML process diagram does not contain feedbacks – they are hidden in the process lower levels of representation. Unlike UML, the extended P/p graph contains feedbacks. The UML process diagram provides information about the resources, documents and the organisational units. The same information is represented in the supporting tables of products in the extended P/p model.

The following observation can be made by comparing both approaches. The extended P/p model provides a compact and concise representation of the business process. Unlike it, the UML process diagram lacks important information concerning the process and cannot be used as a single representation tool without being supplemented by several other UML diagrams.

Since it is often required to model the use of the resources employed in a process, the process diagrams are frequently complemented by class or object diagrams of the resource usage. In this case study the resources related to the process discussed above are represented by a Resource Use pattern [Eriksson and Penker 2000]. This pattern connects the actual use of resources to the process and its instances. The class diagram of the resource use for the main business process and its subprocesses can be found in the Appendix B. All the class diagrams are created with the help of the UML modelling tool ArgoUML 0.12 [ArgoUML].

Resource Use Patterns provide a good illustration of the actual resources employed by a given business process. Unfortunately, there is no similar representation in the extended P/p methodology. The resource use is not separately specified in the extended P/p model and the resources are described in the supporting tables complementing the P/p graph representation. Therefore, one of the advantages of the UML is that Resource Use Pattern presents more information concerning the process resources and their consumption, catalyst, production or refinement.

For more detailed examination of the processes in this case study activity diagrams should be analysed. The activity diagrams are used to describe workflows, the actions performed during an operation in a class, similar to traditional program flowcharts [Eriksson and Penker 2000]. In addition, the activity diagrams are used to describe business processes and workflows in the context of organisations.

All the activity diagrams presented here are created with the help of the UML modelling tool ArgoUML 0.12. Unfortunately, this tool does not support the Eriksson-Penker business extensions and there is not a symbol for representing events. Therefore some of the events are described as activities and others are omitted.

The activity diagram of the P&N subprocess discussed in the previous section is shown in [Fig. 3.7]. The process is triggered by a customer inquiry and terminates by an order received from the customer.

The following observation could be made when the subprocess in [Fig. 3.7] is compared with the extended P/p graph presented in [Fig. 3.5]. The UML activity diagram is an adequate representation of this subprocess with all its activities and events. At the same time this representation does not contain information about the resources, the documents and organisational units that is a disadvantage. In the extended P/p model such data is stored in the supporting tables of products. In addition, the feedbacks are not adequately represented. On the contrary, the extended P/p model provides a proper representation of feedbacks, formal and graphical, and defines the associated with them comparators, actuators and sensors. Thus, it can be concluded that UML activity diagrams are not sufficient on their own to represent fully a business process and they have to be complemented by process diagrams at least.

Process Feedback is a Process Modelling pattern that evaluates the outcome of a business process and based on such evaluations adjusts the process in order to achieve its goal [Eriksson and Penker 2000]. The process feedback pattern of the main business process is presented in [Fig. 3.8]. This pattern is combined with the Action Workflow pattern defined by [Eriksson and Penker 2000].

The action workflow pattern can be applied on both the macro level (interactions between two business processes) and the micro level (actions inside the process). The process feedback pattern in [Fig. 3.8] shows the actions taken inside the process that include the following subprocesses: Preparation, Negotiation, Accomplishment and Acceptance. The input and output resources for every subprocess are described and the feedback between the Negotiation and Preparation processes is represented as information resource "Feedback on the quotation". The output resource "Quotation" of the Preparation process is subject to changes in order to achieve the goal of this process – to satisfy customer requirements. This is done during the Negotiation process and the outcome of this process is fed back to the Preparation process.

Consider the differences concerning the feedback representations in UML and the extended P/p graph. In UML process feedback patterns the feedback is represented as information resource while in the extended P/p models it is formally and graphically represented as a process together with its supporting table. Thus, it can be concluded that the extended P/p model provides a better and a richer representation of feedbacks.

Finally, the UML model must include all its diagrams, process and activity diagrams, resource use and process feedback patterns, to represent a business process completely while the extended P/p model consisting only of a P/p graph with its supporting tables provides the same information and allows the entire business process to be modelled.

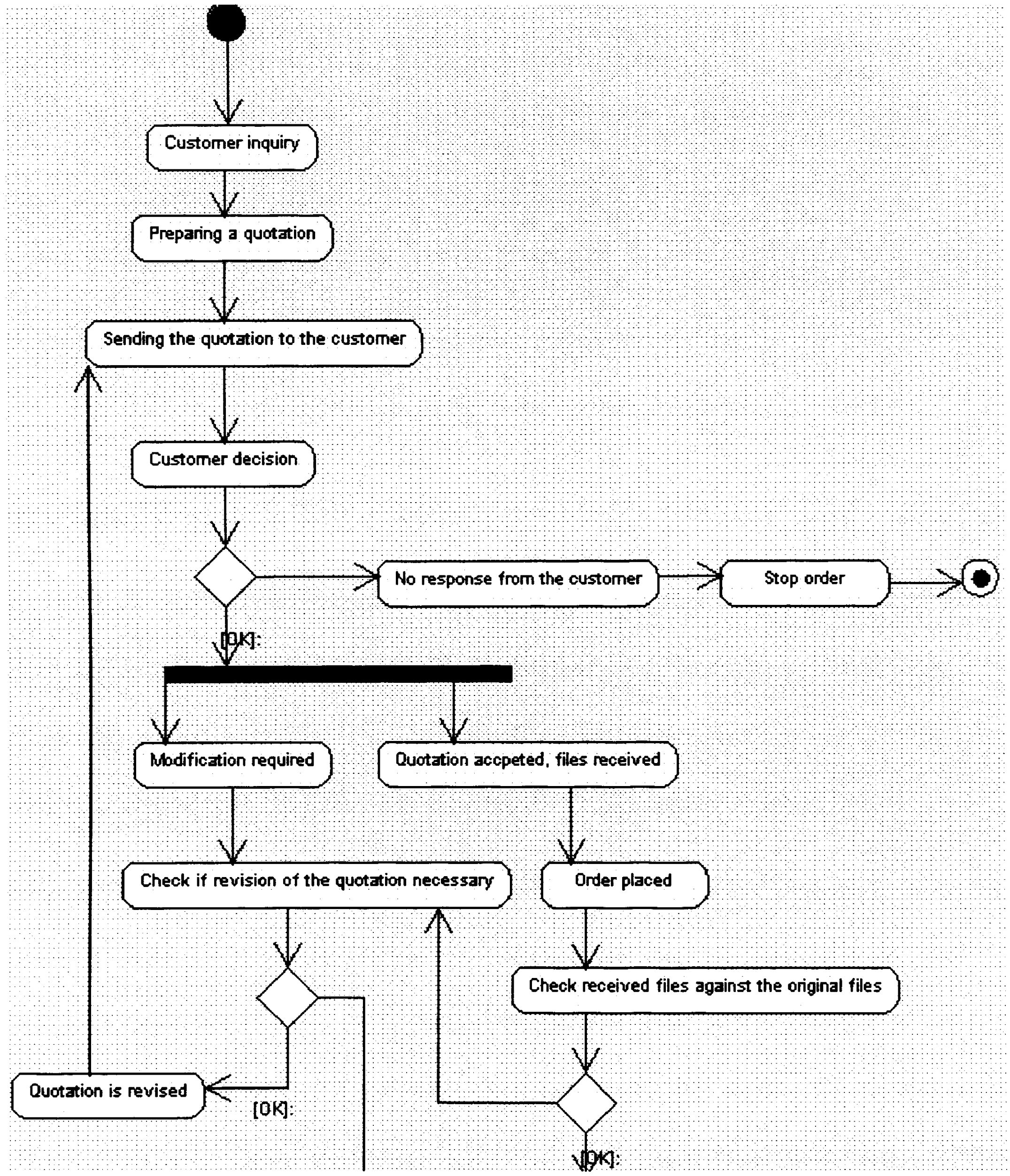


Fig. 3.7 - Activity diagram of the Preparation and Negotiation subprocesses

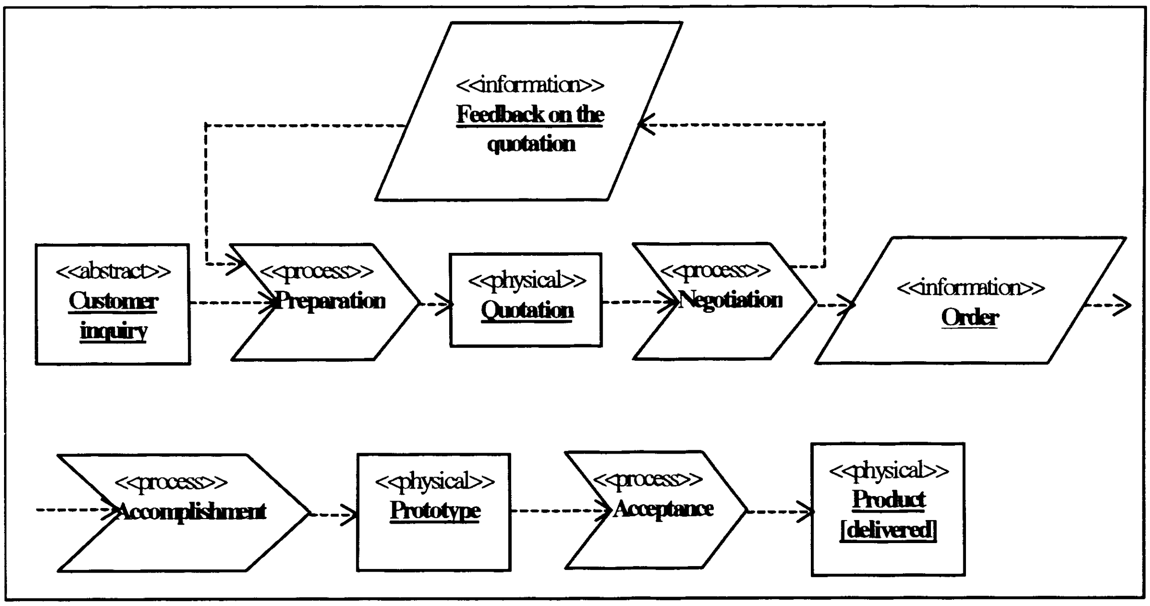


Fig. 3.8 - Process feedback pattern for the main business process

3.6 Discussion

In this research, the modelling capabilities of the extended P/p methodology were described and compared to those of UML. A number of differences between these two modelling approaches were identified in regards to their representation capabilities. The main differences between the UML and the extended P/p models are listed below:

- UML was initially developed to model the architecture of software systems. Therefore only after some adaptation could it be applied for business process modelling. Business systems have many concepts that were never intended or suitable to be executed as a software program, for example people working in a particular business, manufacturing equipment and rules and goals that drive the business processes. To address these limitations a set of extensions were incorporated into UML, called Eriksson-Penker Business Extensions. These extensions provide solutions to some of the problems but are not sufficient to overcome all limitations. Unlike UML, extended P/p methodology relies on concepts specifically defined to model business processes, such as "product", "process", "subprocess", "time", "cost". At the same time the concept of "feedback" and associated with it concepts of "comparator", "actuator" and "sensor" are introduced from the Control Theory to increase its representation capabilities. This research demonstrates that these concepts can be easily adopted for this purpose and are natural extensions of the P/p methodology.

- Since UML relies on nine different types of diagrams to model a specific static or dynamic aspects of a given system, there is no process model, which represents the whole system. In contrast, the extended P/p graph is a representation, which defines the whole business process.

- Important information concerning the business processes and their execution is not available in the UML diagrams. For example, some information about triggering and termination of events can be found only in statechart and activity diagrams. There is no information about the organisational units involved in the process, or the documents supporting it. Only hints about such information could be found in process diagrams, provided by the Eriksson-Penker Business Extensions. On the contrary, the extended P/p graph provides additional information regarding the business process in the form of tables (Tables of products, processes, feedbacks, product, process and feedback attributes), which enables the people using it to grasp better different issues concerning the process. In the P/p models the events are represented as products and the organisational units and the documents are considered as process attributes.

- UML standardises the notations necessary to describe a process, but it does not provide a methodology to produce such description, for example defining the order in which different activities should be executed, and a mechanism to monitor and control their execution. The extended P/p methodology provides a structured way for creating process descriptions in the form of P/p models. Additionally, all concepts of this methodology are formally defined, which facilitate the modelling process.

- Though the UML process diagram describes business processes with their resources, input and output products and goals, it does not provide any information about the attributes of these objects. At the same time the extended P/p model represents the products, processes and feedbacks with their attributes, including attribute codes, attribute names, values and dimensions, together with the relationships between these attributes.

- Activity diagrams describe the steps of the business processes but they do not include any information about the organisational units involved, the resources used, the products related to them or the time durations of the activities. On the contrary, all this information about organisational units, resources, products and times, is defined in the proposed P/p model. The extended P/p graph represents graphically products, processes and feedbacks together with their respective time instants and supporting tables, and also provides information about the organisational units, resources and documents related to the business process.

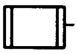
- Feedbacks in UML are only vaguely defined in the process feedback patterns. The extended P/p methodology offers a well-defined mechanism for describing the feedbacks and their elements, including their formal representations in P/p graphs.

Thus, taking into account the above listed differences between UML and the proposed extensions to the P/p methodology, it could be concluded that the proposed approach is much more suitable for modelling business processes. The extensions discussed in this research expand significantly the representation capabilities of the P/p models and address the specific needs of project managers and teams working on large projects or in geographically dispersed locations.

3.7 Summary

In this chapter a set of extensions to the P/p methodology are proposed that address the specific requirements of business process modelling. The limitations of the P/p methodology [Kaposi and Myers 2001] when applied to business process modelling are identified and then techniques to overcome them are proposed. In particular, the following extensions to the P/p methodology are proposed:

- Feedbacks are incorporated and a proper formalism for representing them is defined.
- Since feedbacks are applied, it is required that products have two (or more) different time stamps (a set of time stamps). Thus, time durations, similar to those defined for processes, are introduced for each product.
- Each feedback included in the model has a formal definition, graphical notation and attributes stored in supporting tables.
- Revised definitions and formal representations of products and processes are introduced.

- New attributes are included in the definitions of the products and processes in order to represent feedbacks.
- New symbols are incorporated in the extended P/p graph, such as $\otimes$ - comparator,  - actuator,  - sensor and 

- feedback system.

These extensions to the P/p methodology allow more accurate, clear and easily readable graphical representations to be created, which facilitates the modelling of business processes. All products, processes and feedbacks are presented with their attributes, specified in supporting tables. P/p graphs offer a comprehensive instrument for operational and quality management.

Based on a comparison with the original P/p methodology and UML, the proposed approach proved to be more suitable for solving business modelling tasks and process-oriented problems.

Chapter 4 - Benchmarking of business processes using the extended Product/process methodology

In Chapter 3, extensions to the P/p methodology [Kaposi and Myers 2001] were proposed to overcome some of its limitations. In this chapter, a methodology for benchmarking business processes based on [Spendolini 1992] and the extended P/p methodology is described and factors to be considered identified. The proposed methodology is validated by examining variations of quantitative data, cost, time and quality, resulting from varying some process attributes of a process. The benefits of the proposed benchmarking methodology are discussed.

4.1 Benchmarking and benchmarking factors

4.1.1 Benchmarking – definition and overview

Benchmarking is a search for industry best practices that lead to superior performance. Interest in benchmarking has increased steadily since 1979 when it was first introduced by Xerox [Camp 1989]. Today it is widely used as a tool. In most cases, benchmarking requires the performance of two organisations to be compared and is usually a component of a continuous improvement process. Many regard benchmarking as a method for analysing key performance indicators of companies, often financial, in order to rank them or compare their performance against an industry average. In particular, benchmarking includes:

- Measuring the performance levels of two companies, both for comparison and for registering improvements.

- Identifying areas for improvements.
- Carrying out improvements resulting from such benchmarking studies.

Four different types of benchmarking could be distinguished [Camp 1989]:

- **Internal benchmarking** – comparing the performance of units or departments within one organisation.
- **Competitive benchmarking** – comparing the performance of a company against its direct competitor. In this case, products or services and business processes could be compared. "Reverse engineering" could be used for product benchmarking.
- **Functional benchmarking** – comparing particular business practices in a company against the best practice of a sector or industry.
- **Generic benchmarking** – search for best practices irrespective of industry. This is similar to functional benchmarking but the aim is to compare with the best in class practices cross industrial sectors and different industries.

Before performing benchmarking of a business process, the factors influencing the process performance should be identified and a benchmarking methodology defined. In the next section the main factors that should be considered when benchmarking a business process are discussed and in Section 4.2 a benchmarking methodology is proposed that builds upon the extended P/p methodology.

4.1.2 Benchmarking factors for business processes

The factors that should be considered when benchmarking a business process are discussed and then demonstrated on the case study described in the previous chapter. In this chapter, the whole business process employed in the development of a prototype of golf training device is reviewed in order to demonstrate better the influence of process attributes on the benchmarking factors.

The Process Chain Diagram (PCD) of this business process is shown in [Fig. 4.1]. The P/p graph and the supporting tables that provide more detailed information about the processes and their products are defined by applying the extended P/p methodology. The extended P/p graph of the business process is presented in [Fig. 4.2] and the supporting tables can be found in Appendix A. The Prototyping subprocess is considered as the most important subprocess of the Main Business Process (MBP) and therefore is fully explored. This subprocess contains another subprocess – Quality check, which is also described in detail. The PCD of the Prototyping subprocess together with its respective extended P/p graph and the supporting tables are shown in Appendix C.

4.1.3 Cost and time evaluation

The evaluation of the cost and time associated with a particular business process could be done by applying the extended P/p methodology. Cost and time are among the set of process attributes used in the extended P/p model. Thus, to carry out this evaluation it is just necessary to calculate the sum of all costs and times associated with the execution of the process activities involved in the particular process. **Table 4.1** shows how the overall cost and time of the business processes in [Fig. 4.1] could be evaluated.

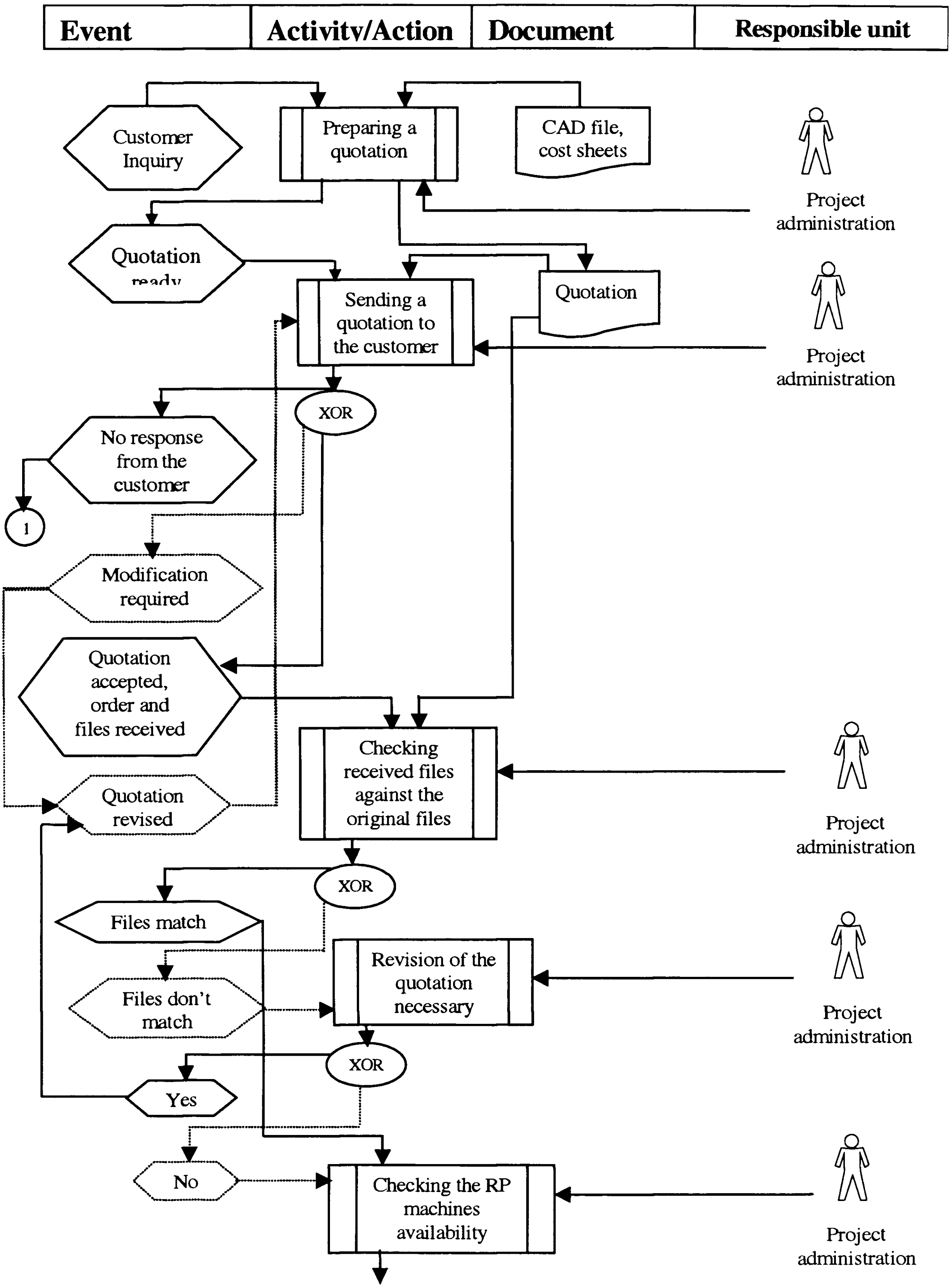


Fig. 4.1 - Process chain diagram of the MBP (continued)

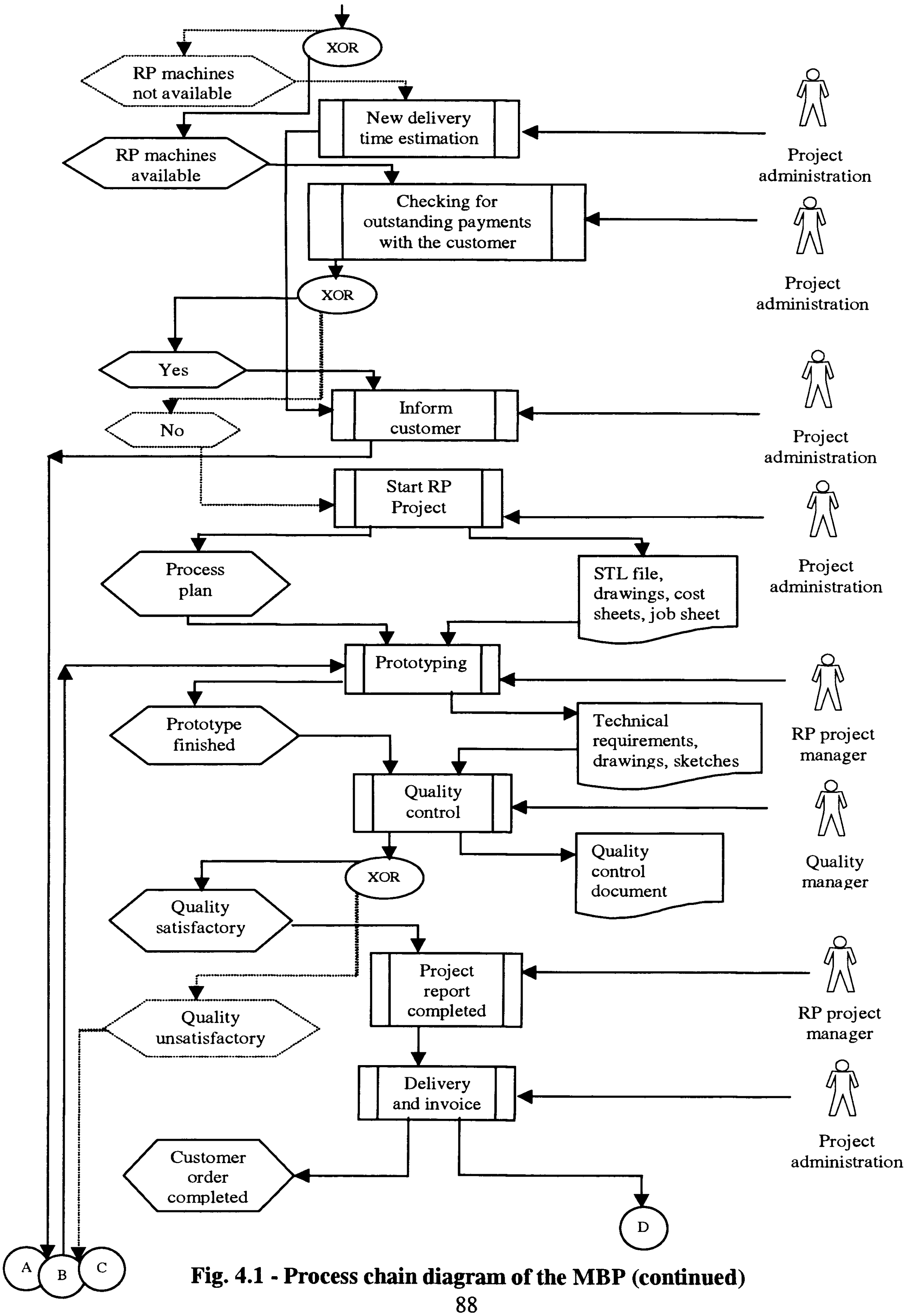


Fig. 4.1 - Process chain diagram of the MBP (continued)

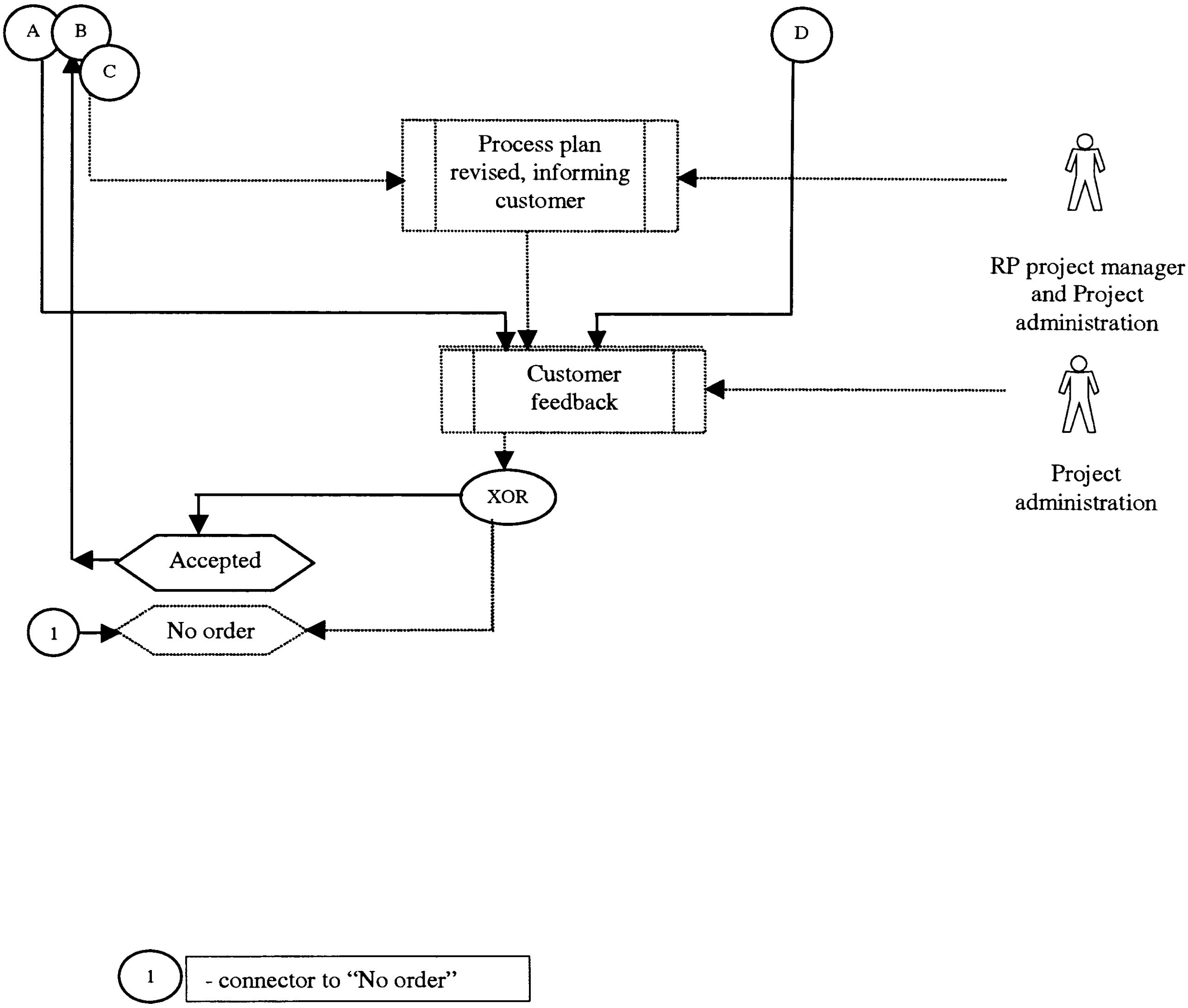


Fig. 4.1 - Process chain diagram of the MBP

In Table 4.2 the time and cost of the feedback processes of the same business process are calculated, similarly. Table 4.3 shows in detail the times and costs of the activities belonging to the Prototyping subprocess, together with the estimation of its overall time and cost. Table 4.4 represents the estimated time and cost of the feedback processes associated with this subprocess. Finally, Table 4.5 provides information about the time and cost associated with the Quality check subprocess.

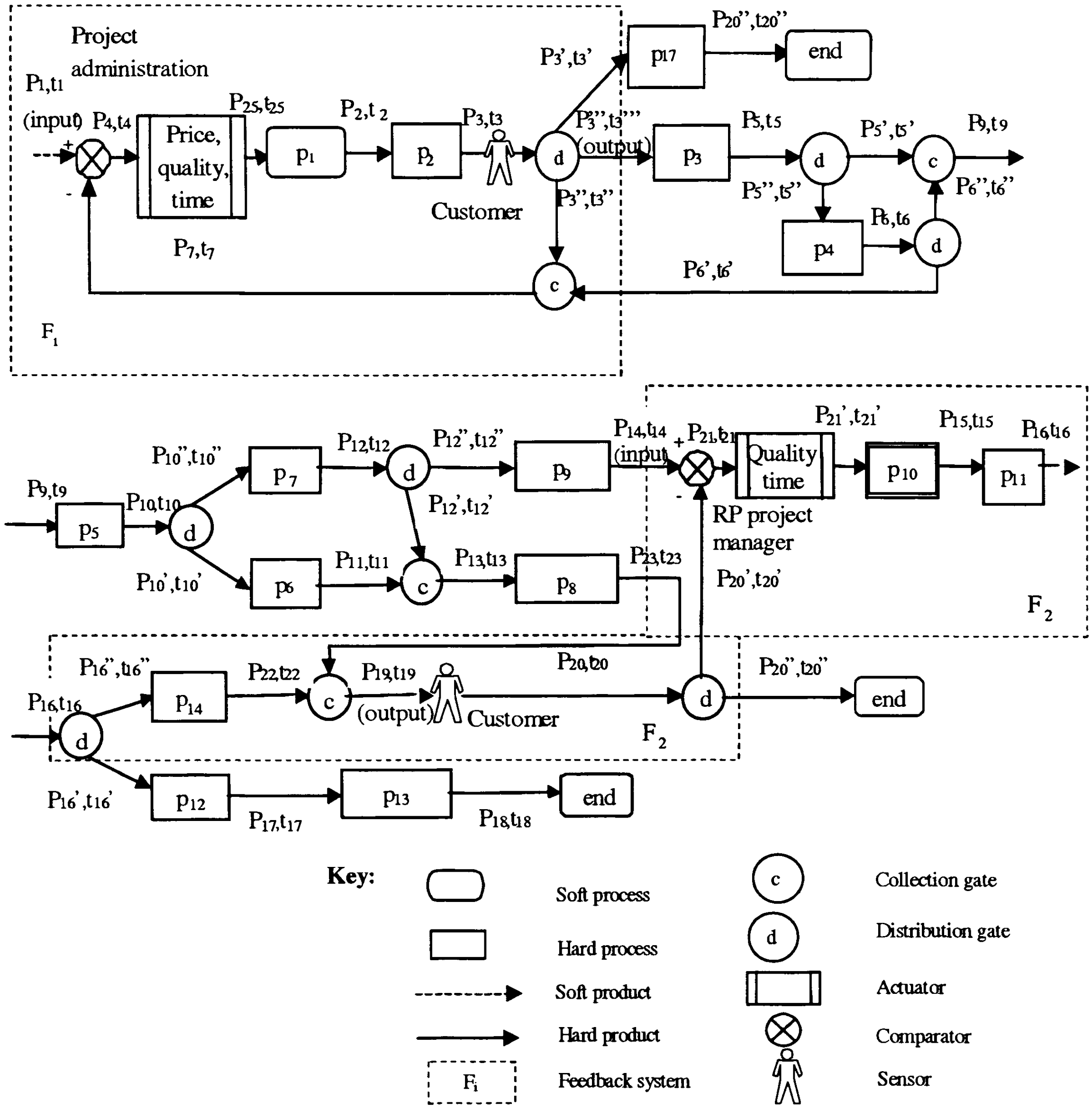


Fig. 4.2 - Extended P/p graph of the MBP

The data for the process times and costs used in these calculations are approximate. The column "Outputs" includes information about decision activities with two possible outputs – "Yes" and "No" and corresponding probability values are assigned to them in %. The only exception is process p_2, which has three possible outputs, "Yes", "No" and

"Cancelled". These outputs can generate different process scenarios thus the estimation of the time and cost associated with a given business process will vary.

Process	Description	Owner	Time	Cost, £	Outputs
p_1	Preparing a quotation	Project administration	12 hrs	75	-
p_2	Sending a quotation to the customer	Project administration	0.2 hrs	5	Yes – 60% No – 35% Cancelled – 5%
p_3	Checking the received files against the original files	Project administration	0.2 hrs	5	Yes – 70% No – 30%
p_4	Revision of the quotation necessary	Project administration	0.2 hrs	3	Yes – 30% No – 70%
p_5	Checking the RP machines' availability	Project administration	0.5 hrs	3	Yes – 85% No – 15%
p_6	New delivery time estimated	Project administration	0.5 hrs	10	-
p_7	Checking for outstanding payments with the customer	Project administration	0.2 hrs	3	Yes – 20% No – 80%
p_8	Inform customer	Project administration	0.2 hrs	5	-
p_9	Start RP project	Project administration	0.2 hrs	3	-
p_{10}	Prototyping	RP project manager	43 hrs	612	-
p_{11}	Quality control	Quality manager	1 hrs	25	Yes – 75% No – 25%
p_{12}	Project report	RP project manager	3 hrs	20	-
p_{13}	Delivery and invoice	Project administration	24 hrs	100	-
p_{14}	Process plan revised, inform customer	RP project manager and project administration	3 hrs	10	-
p_{15}	Customer feedback	Project administration	12 hrs	5	Yes – 85% No – 15%
p_{16}	Quotation is revised	Project administration	5 hrs	20	-
p_{17}	Stop order	Project administration	0.2 hrs	1	-
			Total time	**Total cost**	
			105.4 hrs	£ 905	

Table 4.1 - Estimation of time and cost associated with the MBP processes

Feedback	Description	Time	Cost, £	Owner	Outputs
F_1	Customer feedback for the quotation	24 hrs	5	Project administrator	-
F_2	Customer feedback for the process plan	24 hrs	5	RP project manager	-
		Total time	**Total cost**		
		48 hrs	£ 10		

Table 4.2- Estimation of time and cost associated with the MBP feedbacks

Process	Description	Owner	Time	Cost, £	Outputs
p_1	Check for STL files availability	RP project manager	0.1hrs	1	Yes – 90% No – 10%
p_2	Solid model created	Project engineer	2 hrs	40	-
p_3	Checking for errors in STL file	Project engineer	0.5 hrs	5	Yes – 12% No – 88%
p_4	Correct errors in STL file	Project engineer	1 hrs	15	-
p_5	Checking which SLS material and machine will be used	Project engineer	0.1hrs	1	-
p_6	Checking if the part is too big	Project engineer	0.1hrs	1	Yes – 20% No – 80%
p_7	Part orientation and scaling	Project engineer	0.2 hrs	5	-
p_8	Splitting parts	Project engineer	0.5 hrs	10	-
p_9	Arranging the parts in the build envelope	Project engineer	0.2 hrs	5	-
p_{10}	Setting up process parameters	Project engineer	0.2 hrs	5	-
p_{11}	Checking if SLS machine is EOS or DTM	Project engineer	0.2 hrs	3	Yes – 70% No – 30%
p_{12}	Generation of the slice file	Project engineer	1 hrs	10	-
p_{13}	Check if change of material is required	Project engineer	0.1 hrs	2	Yes – 70% No – 30%
p_{14}	Change material	Project manager	0.2 hrs	5	-
p_{15}	Preparation of the SLS machine	SLS project manager	1 hrs	10	-
p_{16}	SLS processing	SLS project manager	25 hrs	300	-
p_{17}	Cleaning and post-processing	SLS project manager	2 hrs	50	-
p_{18} (sub-process)	First quality check	Quality control manager	1 hrs	25	-
p_{24}	Check if joining parts is required	SLS project manager	0.1 hrs	1	Yes – 20% No – 80%
p_{25}	Joining large parts	SLS project manager	1 hrs	10	-
p_{26} (sub-process)	Second quality check	Quality control manager	1 hrs	25	-
p_{27}	Check if additional finishing required	SLS project manager	0.1 hrs	1	Yes- 85% No – 15%
p_{28}	Additional finishing	SLS project manager	2 hrs	20	-
p_{29}	Check if painting is required	SLS project manager	0.1 hrs	1	Yes – 90% No – 10%
p_{30}	Painting	RP manager	1 hrs	10	-
p_{31} (sub-process)	Final quality check	Quality control manager	1 hrs	25	-
			Total time	**Total cost**	
			41.7 hrs	£ 586	

Table 4.3 - Estimation of time and cost associated with the processes for the Prototyping subprocess

Feedback	Description	Time	Cost, £	Owner	Outputs
F_1	Feedback for splitting the parts	5 min	1	Project engineer	-
F_2	Feedback for quality check	60 min	25	Quality manager	-
		Total time	**Total cost**		
		65 min	£ 26		

Table 4.4 - Estimation of time and cost associated with the feedbacks of the Prototyping subprocess

Process	Description	Owner	Time	Cost, £	Outputs
p_{18}	Quality check	Quality control manager	20 min	7	Yes – 75% No – 25%
p_{19}	Check if correction possible	SLS project manager	5 min	1	Yes – 95% No – 5%
p_{20}	Correction	SLS project manager	15 min	10	-
p_{21}	Scrapping the failed parts	SLS project manager	2 min	1	-
p_{22}	Rebuilding the parts required	SLS project manager	2 min	1	Yes – 3% No – 97%
p_{23}	Calibration of the parts	SLS project manager	10 min	5	-
			Total time	**Total cost**	
			54 min	£ 25	

Table 4.5 - Estimation of time and cost associated with the processes of the Quality check subprocess

4.1.4 Evaluation of the process efficiency

To define the quality of a given process its efficiency should be assessed. The efficiency of a process is defined in the quality standard ISO/FDIS 9000:2000 as "the relationship between the result achieved and the resources used". However, in this research the definition given in [Kaposi and Myers 2001] for an economic system is used. In particular, the efficiency of an economic system is considered "the ratio of monetary value of the output to the monetary value of the input":

$$a_{economic\ efficiency} = \frac{monetary\ value\ of\ output}{monetary\ value\ of\ input} \qquad (4.1),$$

where $0 \leq a_{economic\ efficiency} <$ infinity (4.2)

4.1.5 Measuring the quality of a business process

In the international quality standard ISO/FDIS 9000:2000 quality is defined as "the degree to which a set of inherent characteristics fulfils requirements". A different definition was introduced by Kaposi and Myers. In this definition quality is considered as the "degree to which the characteristics of a system fulfil the requirements of interested parties".

Thus, it implies that to assess the quality of a given process the requirements towards the products that it generates should be taken into account. Also, this definition indicates that quality encompasses a minimal set of characteristics and properties and this set should be complete to judge about the process quality.

In order to measure the quality of a product it is important to describe it using quantitative terms. The general approach for assessing the quality of a given process encompasses the identification of its properties and the way to measure them. Such approaches are frequently found in the literature, i.e. [Hommes 2001], [Gouscos et al 2003] and [Kaposi et al., 1994] where to assess quality it is required to identify quality properties and also to describe procedures to measure these properties in an objective way. The term "properties" in this definition can be seen as a synonym for "qualities", "attributes", "characteristics" or "features" and therefore these terms are often used interchangeably in literature.

The quality of a business process depends on its characteristics' values, i.e. the process attributes and their values. Considering the formal representation of a process presented in Section 3.3.2, the attributes, which strongly influence the quality of the business process, are cost and time duration. The quality of a process is higher if the cost associated with its execution is low and the time required for this shorter. The process efficiency also has an impact on the quality of the business process, i.e. the higher the process efficiency, the higher is its quality. Therefore, the quality of a business process can be expressed as a function of the three process attributes: process efficiency, process cost and process time.

$$Q = \mathrm{f}(\max a, \min c, \min t) \qquad (4.3)$$

where Q is the quality of the business process, a is the process efficiency, c is the cost of the process and t is its time duration.

The other process attributes, such as domain, transfer function, status, owner and feedback also have an impact on the process quality, as summarised in **Table 4.6**.

Process attribute code	Process attribute	Quality requirements
pa_1	Domain	Clearly defined domain
pa_2	Transfer function	Well-described transfer function
pa_3	Status	Free status
pa_4	Owner	Assigned owner
pa_5	Feedback	Available and prompt feedback

Table 4.6 - Process attributes influencing the process quality

The influence of these process attributes on quality could be taken into account using coefficient ***k***:

$$k = \alpha_1 pa_1 + \alpha_2 pa_2 + \alpha_3 pa_3 + \alpha_4 pa_4 + \alpha_5 pa_5 \qquad (4.4)$$

where the process attributes pa_1, pa_2, pa_3, pa_4 and pa_5 are weighted according to their influence on the quality. α_1, α_2, α_3, α_4 and α_5 are the weights assigned to each process attribute and reflect the level of their influence on the process quality. The weights of the process attributes are determined by applying the Analytic Hierarchy Process (AHP) [Saaty 1980]. The AHP is a selection process, which includes the following four steps, as discusses by [Drake 1998]:

1. Decide upon the criteria for selection, i.e. the process attributes.
2. Rate the relative importance of these criteria using pair-wise comparison.
3. Rate each potential choice relative to each other choice on the basis of each selection criterion by performing pair-wise comparisons of the choices.
4. Combine the ratings derived in steps 2 and 3 to obtain an overall relative rating for each potential choice.

The first step is already done by selecting the process attributes influencing the process quality in **Table 4.6**. In the second step pair-wise comparison of the process attributes importance is accomplished in regards to the scale shown in **Table 4.7** adopted by [Saaty 1980].

Comparative importance	Definition	Explanation
1	Equally important	Two decision elements (e.g. indicators) equally influence the parent decision element.
3	Moderately more important	One decision element is moderately more influential than the other.
5	Strongly more important	One decision element has stronger influence than the other.
7	Very strongly more important	One decision element has significantly more influence over the other.
9	Extremely more important	The difference between influences of the two decision elements is extremely significant.
2, 4, 6, 8	Intermediate judgement values	Judgement values between equally, moderately, strongly, very strongly, and extremely.
Reciprocals		If v is the judgement value when I is compared to j, then 1/v is the judgement value when j is compared to i.

Table 4.7 - Pair-wise comparison values [Saaty 1980]

If all process attributes selected in **Table 4.6** are designated with pa_{ij}, then according to the pair-wise comparison values pa_{ii}=1. Furthermore, if $pa_{ij}=l$ then $pa_{ji}=1/l$. Following these observations the pair-wise comparison of the importance of the process attributes is carried out resulting in a matrix as shown in **Table 4.8**. The weights of the process attributes in this table are determined by experts as a result of specially designed questionnaire and used throughout the case study. Finally, the overall weight assigned to each process attribute is determined by simple calculations. This weight will be between

0 and 1, the total weights will add up to 1. The results represent the normalised pair-wise rating of the process attributes in **Table 4.9**. It is obvious that the process attribute feedback (pa_5) has the biggest weight and therefore has the strongest influence on the business process quality. The row average in Table 4.9 produces the weights of the process attributes α_1, α_2, α_3, α_4 and α_5 as defined in equation (4). Therefore, α_1=0.043, α_2=0.059, α_3=0.221, α_4=0.136 and α_5=0.531, which leads to the following equation:

$$k = 0.043pa_1 + 0.059pa_2 + 0.221pa_3 + 0.136pa_4 + 0.531pa_5 \qquad (4.5)$$

Thus, if all these process attributes are missing, the coefficient k = 0. If all process attributes are present, then k=1.

The third and fourth steps of the AHP are not required for the purpose of this research, which aims only to determine the influence of the process attributes by assigning weights to them. Further on the AHP method can be used to evaluate business process alternatives according to these criteria (i.e. process attributes). Matrices similar to the ones in Table **4.8** and **4.9** have to be build for each process alternative and finally the ratings derived from the second and third steps have to be combined to obtain the overall rating for each alternative.

	pa_1	pa_2	pa_3	pa_4	pa_5
pa_1	1	1/2	1/5	1/4	1/7
pa_2	2	1	1/5	1/4	1/7
pa_3	5	5	1	3	1/5
pa_4	4	4	1/3	1	1/6
pa_5	7	7	5	6	1

Table 4.8 - Pair-wise comparison of the process attributes

	pa_1	pa_2	pa_3	pa_4	pa_5	*Row average*
pa_1	0.053	0.029	0.030	0.024	0.080	0.043
pa_2	0.105	0.057	0.030	0.024	0.080	0.059
pa_3	0.263	0.286	0.149	0.293	0.112	0.221
pa_4	0.211	0.229	0.050	0.098	0.094	0.136
pa_5	0.368	0.400	0.743	0.585	0.561	0.531

Table 4.9 - Normalised pair-wise rating of the process attributes

After determining the influence of the process attributes on the quality of the business process, formula (3) can then be redefined, as follows:

$$Q = f(\max a, \min c, \min t, k) \quad (4.6)$$

The function for Q (6) can be defined further to measure the quality of the process in percents (%) by multiplying it by 100 as in formula (7). The quality Q is normalised by multiplying the coefficient *k* by 10 in limits of 0% to 100% similarly to the Baldridge Award Scoring System [Evans and Lindsay 1996].

$$Q = \frac{a * k * 10}{c + t} * 100\ \% \quad (4.7)$$

Table 4.10 provides guidelines for assigning qualitative measures to processes based on the value of Q. These guidelines are based on the Baldrige Award Scoring Guidelines [Evans and Lindsay 1996] and are confirmed by the carried out case studies in this research concerning modelling of different business processes.

Quantitative measure	Qualitative measure
$0\ \% \le Q < 10\%$	Unsatisfactory quality (failure)
$10\% \le Q < 40\%$	Satisfactory quality
$40\% \le Q < 70\%$	Good quality
$70\% \le Q < 90\%$	Very good quality
$90\% \le Q < 100\%$	Excellent quality

Table 4.10 - Guidelines for qualitative assessment of process quality

4.2 Benchmarking methodology for business processes

Benchmarking approaches vary both in the way the performance assessment models are conceived and how in practice the methodology is applied. There is a trend to develop such models in accordance to the specific characteristics and requirements of the benchmarking partners. The benchmarking methodology is widely considered as a structured process following sequential steps defined in the Deming continuous improvement cycle [Ribeiro et al 2003], known also as the PDCA cycle: Plan (Plan), Do (Collect), Check (Analyse) and Act (Adapt). The diagram in [Fig. 4.3], adopted from the TQM section of the HCi Journal of electronic publications and [Deming 1989], lists the tools and techniques, which can be used to complete each stage of the PDCA Cycle.

4.2.1 Benchmarking methodology for business processes

The benchmarking methodology proposed in this study follows the stages of the PDCA cycle that are also used in Spendolini's benchmarking methodology [Spendolini 1992]:

Stage 1. Identify what to benchmark.

Stage 2. Form the benchmarking team.

Stage 3. Identify benchmarking partners.

Stage 4. Collect and analyse information.

Stage 5. Take action.

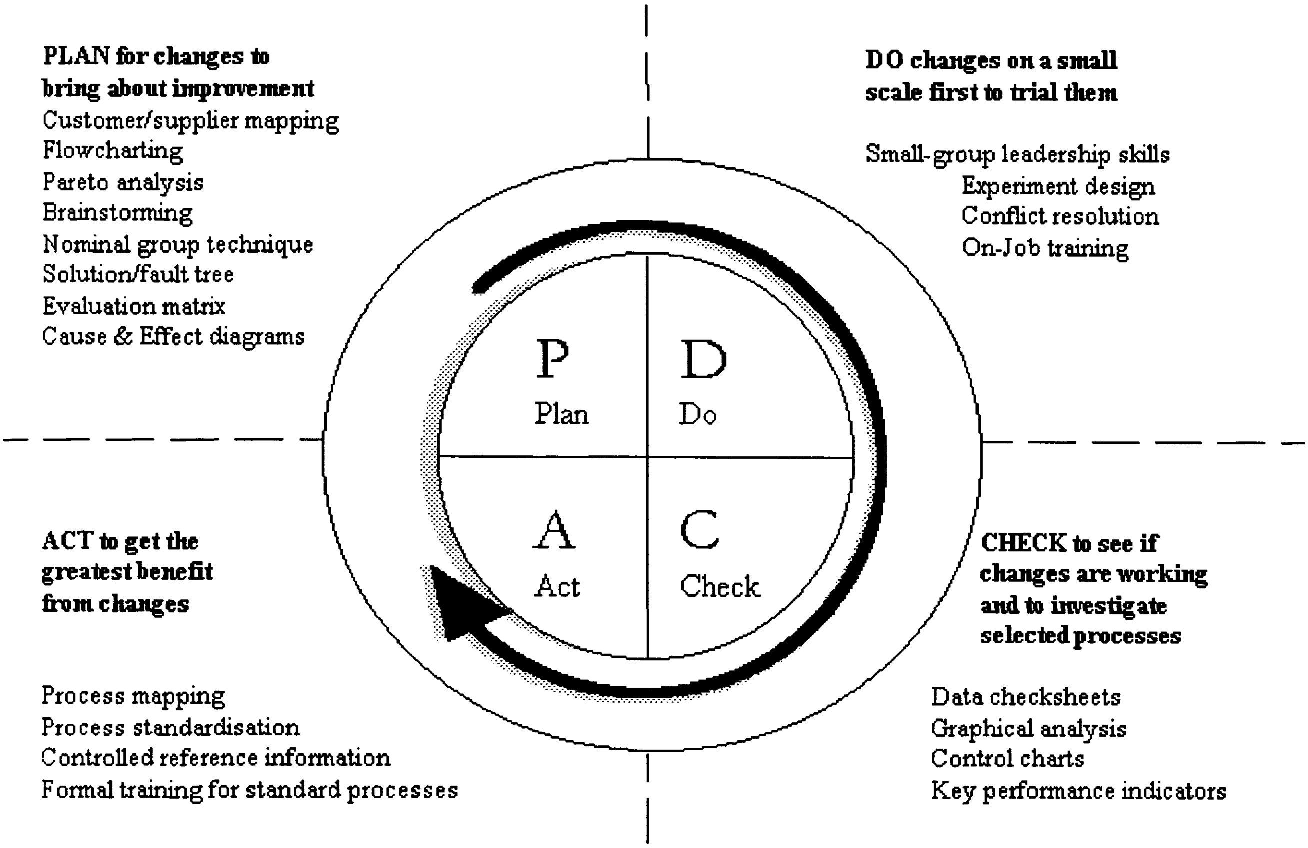


Fig. 4.3 - PDCA cycle of Deming [Deming 1989]

Applying this structured approach for performing benchmarking in combination with the extended P/p model described in Chapter 3 results in a new benchmarking method specifically designed for evaluation of business process models. This method can be used for internal benchmarking of business processes and also for functional benchmarking to compare particular business processes in two or more organisations within the same industry. In addition it could be applied for carrying out a competitive benchmarking when compare performance with a direct product competitor or generic benchmarking in searching for the best practice irrespective of industry.

4.2.2 Benchmarking phases and steps

The benchmarking methodology proposed in this research is represented as a process by applying the extended P/p graph. In particular, following the Deming PDCA cycle, this process has four phases: **Plan, Collect, Analyse** and **Adapt**. The benchmarking approach proposed by Spendolini [Spendolini 1992] is adopted in defining the different phases of the benchmarking process.

The proposed methodology for evaluation of business process models is presented as a process by applying extended P/p graph in [Fig. 4.4]. The P/p graph defines mostly sequential activities but also a feedback process is incorporated to allow a continuous process improvement to take place. The data associated with products, processes and the feedback of the extended P/p model is given in **Appendix D, Tables D.1**, **D.2** and **D.3**.

4.2.3 Phases of the internal benchmarking process

In this study the focus is on the phases required for conducting internal benchmarking. This includes plan, analyse and adapt phases. The scope of the benchmarking exercise is defined together with the algorithm for its execution that includes the following steps:

1. Identify the purpose of the business process model, list all of its functions and its components (products, processes, events, documents, organisational units, time, cost etc.)
2. Identify the benchmarking factors – process cost, time, efficiency and quality.
3. Develop a model to measure the benchmarking factors and the quality of the business process.

4. Conduct a pilot benchmarking exercise to validate the approach for measuring different benchmarking factors and the quality of the business process. This is carried out by comparing the quantitative measures associated with process cost, time, efficiency and quality resulting from different executions of the benchmarking model
   - by varying some process attributes.
   - by applying different methodologies (e.g. P/p, UML, PCD).
   - by changing the business process modelling approach.
5. Analyse the quantitative and qualitative results for the benchmarking factors (by displaying and comparing them using graphics, tables, diagrams etc.)
6. Analyse the benchmarking results for each process modelling methodology by applying different comparison methods.
7. Produce a report about the benchmarking results for the business process model.
8. Make recommendations for improvement of the existing process model to be equally efficient and effective as the best practices.
9. Continue the benchmarking process

A detailed description for conducting the benchmarking exercise to validate the process model in three different dimensions, as stated above, is provided in Chapter 6. In the next section of this chapter an example of applying the proposed benchmarking methodology is presented to illustrate the validation of the process model in the first dimension concerning the comparison of the quantitative results of the benchmarking indicators for the same business process by varying some process attributes.

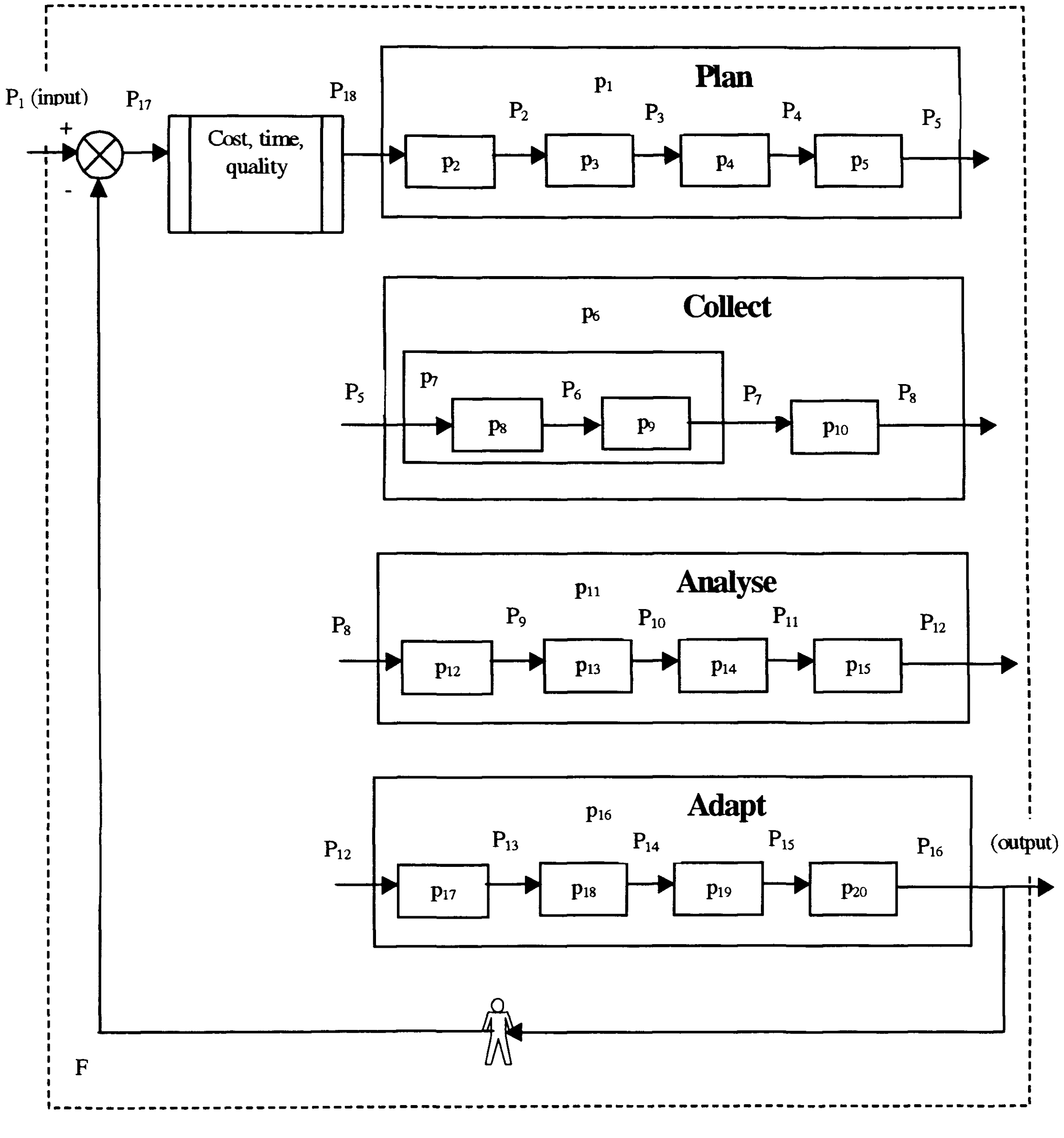


Fig. 4.4 - P/p graph of the benchmarking process adopted from Spendolini

[Spendolini 1992]

4.3 Demonstrative example

The proposed benchmarking methodology is applied on the MBP model to demonstrate its advantages over other benchmarking approaches discussed in [Ribeiro et al 2003]. Firstly, the purpose of the process model, together with its components and attributes, are defined. Then, the benchmarking factors are identified – cost, time, efficiency and quality and a model to measure them together with the quality of the business process is proposed.

Finally, a pilot benchmarking exercise to validate this model is conducted. It involves a comparison of the quantitative results obtained for the same business process when varying some of its attributes.

4.3.1 Cost and time comparison by varying feedback attributes

In Section 4.1.2.1 the times and costs associated with the MBP and its subprocesses are calculated. Using the evaluation results for the MBP feedbacks and its Prototyping subprocess presented in **Table 4.2 and Table 4.4** it is possible to update the maximal time and cost associated with these processes. The results of these estimations are shown in **Table 4.11**.

These results suggest that each new feedback iteration increases the process cost and time, thus affects the performance of the whole business process. In the case of the MBP both feedbacks have the same effect on the process because their times and costs are identical and they both involve a feedback from the customer. Regarding the Prototyping subprocess, the results indicate that the second feedback, concerning the quality checks of the product, has a very strong impact on the process time and cost.

	MBP		Prototyping subprocess	
Scenario	**Max Time, h**	**Max Cost, £**	**Max Time, h**	**Max Cost, £**
Without feedbacks	**105.4**	**905**	**41.7**	**586**
1 iteration for each feedback	**153.4**	**915**	**42.8**	**612**
2 iterations for the first and 1 iteration for the second feedback	**177.4**	**920**	**42.9**	**613**
2 iterations for the second and 1 iteration for the first feedback	**177.4**	**920**	**43.9**	**637**
2 iterations for each feedback	**201.4**	**925**	**43.9**	**638**

Table 4.11 - Comparison of times and costs with varying feedback attributes

The time and the cost of the Prototyping subprocess could be less than the values calculated in Table 4.11. For example, if the process "Checking if the part is too big" has an output "No", then some activities, such as "Splitting parts" and "Arranging the parts in the build envelope" will be unnecessary, saving 0.7 hours of process time and £15 cost.

The analysis of the feedback influence on the process performance has shown that its attributes have a very strong impact on the process cost and time. In particular, the feedbacks increase the process time and cost in a short term, but in a long term it could lead to savings. This is because there is no need to re-design the process model. Thus, if the products from the processes in the model do not satisfy particular customer requirements or do not comply with manufacturing standards, then the MBP will be even more costly and time consuming when feedbacks are not applied.

Another parameter that has a strong influence on the process cost and time is the selected execution path in the model that depends on the process outputs, as discussed in Section 4.1.2.1. Depending on the output of a particular condition, the business process can include different sequences of actions and therefore the times and the costs of the process will vary.

4.3.2 Process efficiency comparison with varying feedback attributes

A quantitative assessment of the MBP process efficiency and its subprocesses could be carried out applying the approach presented in **Section 4.1.2.2**. The economic efficiency of the Quality check subprocess is measured making the assumption that the monetary value of the input and output products are £468 and £493 respectively. Similarly, the economic efficiency of the Prototyping subprocess is measured assuming that initially the feedbacks are not activated. In this case, the monetary value of the input and output products are £112 and £586. Finally, the economic efficiency of the MBP is assessed first, assuming that the feedbacks are not activated. In this case, the monetary value of the input product is £10 and the corresponding value of the output product is £905. All the monetary values used to measure the process efficiency are calculated based on the costs of the relevant processes shown in **Tables 4.1, 4.3** and **4.5** and the costs of the relevant feedbacks in **Tables 4.2** and **4.4**. The measure about the process efficiency obtained in case of varying feedback attributes are presented in **Table 4.12**.

	Process efficiency, $a_{economic\ efficiency}$		
Case	**Subprocess Quality check**	**Subprocess Prototyping**	**Main business process**
Without feedbacks	1.05	5.23	90.5
Both feedbacks performed once	-	5.46	91.5
Both feedbacks performed twice	-	5.68	92.5

Table 4.12 - Comparison of the process efficiencies when varying feedback attributes

The conclusion that could be made from these results is that by applying feedbacks, the economic efficiency of processes increases due to the increase of the monetary value of their outputs. Therefore, the extended P/p models that incorporate feedbacks have a higher economic efficiency than those without feedbacks as it is demonstrated by the results presented in **Table 4.12**. Clearly, the process attribute "feedback" has a strong influence on the process efficiency.

4.3.3 Comparison of process quality with varying feedback attributes

The next step of the benchmarking process requires the quantitative and qualitative results obtained for the benchmarking factors to be analysed. Applying the approach described in **Section 4.1.2.3** the quality of the MBP has been measured for a number of executions of the process where the values for some process attributes were varied, such as domain, transfer function, status, owner and feedback. These executions of the process represent the following cases:

- ***Ideal case:*** the MBP has one feedback with one iteration and the Prototyping subprocess does not have any feedbacks and all process attributes are available;
- ***Case 1:*** the MBP and the Prototyping subprocess do not have any feedbacks and all process attributes except for the feedback are available;
- ***Case 2:*** the MBP has one feedback with one iteration and the Prototyping subprocess has two feedbacks with one iteration each, all process attributes available;
- ***Case 3*** - the Main business process has one feedback with one iteration and the Prototyping subprocess has two feedbacks with one iteration each and all process

attributes are available, but the attribute value of the process status is "busy" and not "free";

- *Case 4:* Both the MBP and the Prototyping subprocess have two feedbacks with one iteration each and all process attributes are available;
- *Case 5:* Both the MBP and the Prototyping subprocess have two feedbacks with one iteration each and all process attributes are available, but the attribute "owner" is not assigned to the process;
- *Case 6:* the MBP has two feedbacks with two iterations each and the Prototyping subprocess has two feedbacks with one iteration each and all process attributes are available;
- *Case 7:* the MBP has two feedbacks with two iterations each and the Prototyping subprocess has two feedbacks with one iteration each and all process attributes are available, but the domain of the process is not specified.

The results from these case studies are given in **Table 4.13** below.

Case	Process efficiency, *a*	Cost, *c*	Time duration, *t*	Coefficient, *k*	Quality, *Q*	Qualitative measure
Ideal case	90.5	£879	104.1 h	0.99	91 %	Excellent
Case 1	90.5	£879	104.1 h	0.46	42 %	Good
Case 2	90.5	£905	105.4 h	0.99	89 %	Very good
Case 3	90.5	£905	105.4 h	0.77	69 %	Good
Case 4	91.5	£915	153.4 h	0.99	85 %	Very good
Case 5	91.5	£915	153.4 h	0.85	73 %	Very good
Case 6	92.5	£925	201.4 h	0.99	81 %	Very good
Case 7	92.5	£925	201.4 h	0.95	78 %	Very good

Table 4.13 - The MBP quality when varying some of its process attributes

The quality of the business process in the context of these seven cases of its executions is compared in [Fig. 4.5]. It demonstrates that every change in the process attributes affects the quality of the business process.

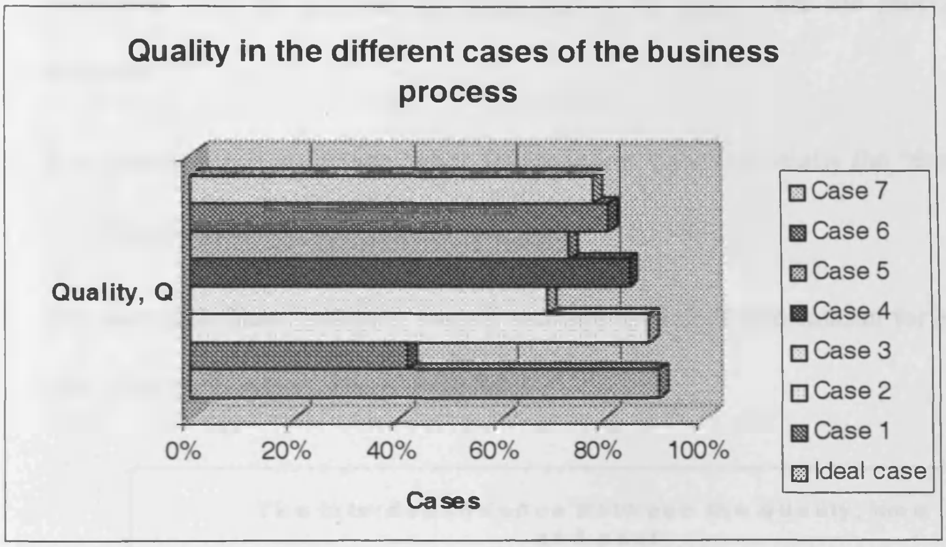


Fig. 4.5 - Comparison of business process quality for seven alternatives of its executions

4.3.4 Discussion

Based on this demonstrative example some conclusions could be made about the interdependence of the three benchmarking factors time, cost and quality. For the seven alternative executions of the MBP the values of these factors are shown in [Fig. 4.6].

By analysing this data some conclusions could be drawn about the proposed approach for measuring these benchmarking factors. In particular:

- There is a linear interdependence between these factors, e.g. between the process efficiency and time, process efficiency and cost, time and cost, respectively.

- The functional interdependence between these benchmarking factors and the process quality is non-linear. The measure proposed to assess the process quality in Section 4.2.2.3 is based on the assumption that the quality increases when costs and time associated with the process decrease and at the same time the process efficiency increases.
- The process quality changes when its attributes vary. Especially the "feedback" has a significant impact on the process quality.
- The identified benchmarking factors provide sufficient information for evaluating the quality of the business process model.

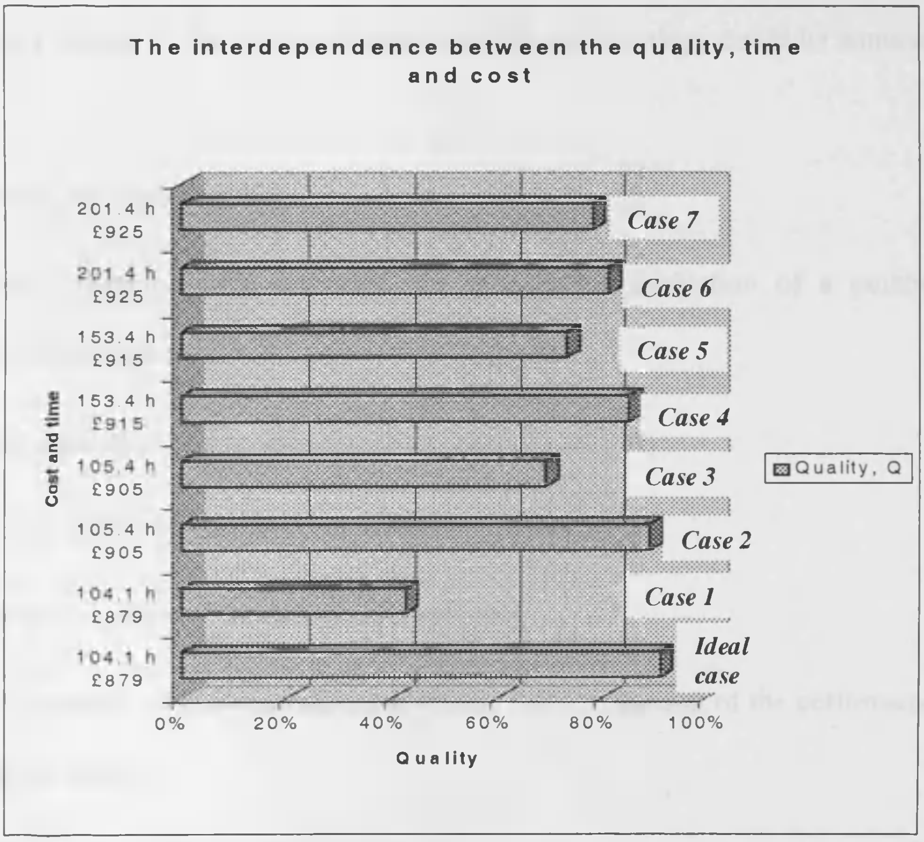


Fig. 4.6 - The interdependence between quality, time and cost

4.4 Application areas and advantages

The proposed benchmarking methodology could be applied to evaluate the performance of business processes. Also it could be used for assessing the quality of business process models. Thus, this methodology could be applied to:

- Assess the influence of different process attributes on the performance of a given business process.
- Evaluate the quality of business process models developed by using different modelling approaches.
- Compare two business processes.

The main advantages of the proposed benchmarking methodology could be summarised as follows:

- easy to use and understand.
- provides a simple formal approach for quantitative evaluation of a number of benchmarking factors.
- provides qualitative and quantitative benchmarking results;
- easy to implement in a workflow system environment.
- easy to use for process simulation and evaluation.
- provides analysis of the benchmarking results and comparison of the performance of the process models.
- provides a method for carrying out comparative studies.

- a cost-effective solution for business process identification, analysis and modelling.
- provides ability to predict the outcome of a radical change on the process sand to recognise the dynamic nature of the process.
- facilitates the introduction of continuous process improvement policy in companies.
- supports business process re-engineering and performance evaluation exercises.
- provides a method for internal, functional and even competitive and generic benchmarking.

4.5 Summary

A benchmarking methodology is described in this chapter for evaluation of business processes and also their models. In particular, this methodology provides a formal approach for measuring the performance of business processes. Also, it could be applied for process simulation and thus provides a solution for analysing alternative business processes or their models. The proposed benchmarking methodology could be employed as a tool for operational and quality management. The evaluation of the process performance and the quality of the business process are achieved by employing the benchmarking factors. A weakness of this methodology is its applicability only to business processes.

The main application areas of the proposed benchmarking methodology are summarised below:

- The methodology could be used as a tool for assessing the influence of different process attributes on the performance of a given business process (internal benchmarking);
- The results obtained by applying it could be utilised for evaluating the quality of business process models developed by implementing different modelling approaches (internal or generic benchmarking);
- It could be employed for comparing business processes (functional or competitive benchmarking).

The proposed method evaluates the quality of the business process and compares different process scenarios by varying different process attributes. Therefore, it leads to reduction of the investment costs related to business process identification, analysis and modelling. Also, it provides the ability to predict the outcome of a radical change in the process and to recognise the dynamic nature of the process and assists the organisation in the continuous process improvement cycle.

Chapter 5 - Enterprise Collaborative Portals for Business Process Modelling

As previously discussed, the business processes of manufacturing enterprises need to be dynamic, especially when highly customised products are manufactured or different projects run simultaneously. Another trend in contemporary manufacturing is the necessity for co-operation between geographically dispersed teams. In this chapter a method for modelling business processes enabling co-ordination of dynamic workflows is discussed in detail. The same case study as presented in Chapter 3 is used to illustrate the proposed algorithm for creating business process models. As a platform for the implementation of the proposed method, an object-oriented approach and agent-based architecture are adopted.

5.1 Problem definition and proposed solution

The review of Business Process Modelling techniques and Enterprise Collaborative Portals (ECP) identified two main problems associated with their application:

- Existing process modelling tools do not focus on resource management and tend to produce non-executable models [Vernadat 1996]. There is also no efficient enterprise integration model that addresses process co-ordination issues in large distributed business environments. A new methodology is therefore required for developing richer models, encompassing all aspects of enterprise modelling, including organisational aspects, resource management, product and activity models;

- There are no solutions addressing the process modelling and co-ordination issues associated with dynamic workflows that could support the collaborative work of geographically dispersed teams. To develop such solutions it is essential that all participants in a project contribute to the creation of a process model that would co-ordinate their joint activities. An environment enabling such collaborative work should be developed [Firestone 1999].

The first of the above problems could be successfully resolved by applying the extended Product/process methodology introduced in Chapter 3.

The second problem can be addressed by using an ECP environment. This environment would provide team members with the necessary enterprise information, such as resources, departmental documents and project details. It would also provide teamwork services, such as video conferencing tools, blackboards and team rooms, to facilitate collaborative business process modelling.

At the start of a project, most of the communication and co-ordination needs can be met by employing tools for collaborative working, mentioned above teamwork services. For example, during the creation of a business process, the ECP environment provides team members with a conference tool for co-operative work on the business process model. The support includes graphical tools and access to all the required enterprise information stored in the corporate database.

By providing a single window onto the information, business processes and tools, the ECP is a very effective medium for dealing with dynamic workflows, especially those supporting geographically dispersed teams. These workflows require rapid reaction and instant feedback from team members to deal with arising new issues.

5.2 Existing tools for solving the identified problem

A product development project usually includes a set of work packages or activities that are executed by different people. In case of complex products developed by multinational company, projects may involve teams at geographically dispersed locations. Thus, at any time, different engineers may work on tasks that are interrelated to one another. The decisions made by one engineer may have significant impact on those made by other engineers. To prevent inconsistency and reduce redundant activities, engineers must collaborate actively and project activities must be well co-ordinated. There is a clear need to agree on efficient mechanism for carrying out such co-ordination [Huang et al. 2000].

Workflow management technology has also been widely used as a tool facilitating co-ordination or collaboration among work centres, especially when information systems are extensively used. Web technology complements the workflow management tools, and web-based user interfaces have been considered as a necessity for workflow management systems. [Miller et al. 1997] quoted a number of web-based or web-enabled workflow management systems in their research and also highlighted several advantages of the web-based workflow management systems, such as the ease of development, installation and use.

The Enterprise Web Portal can help enterprise users to share information and make it available on the Internet, essentially to any electronic device with an IP address and information. Also, it gives an opportunity to users to contribute to a project simultaneously throughout the development cycle by accessing information both shared and collaborated upon within a controlled environment [Rezayat 2000b].

To help realise the full potential of ECP as shared information workspaces a new approach is required in their design. Typically, organisations launch portal development initiatives as a means to reduce internal information publishing costs and enhance corporate information distribution [Rice, 1996; Thyfault, 1996]. In addition, portals can also provide functionality which helps larger groups of people co-operate and work together more efficiently [Small, 1999]. Tight integration with suppliers and customers throughout the entire development cycle is also increasingly essential.

5.3 Approach for creating a richer process model

The interoperation of the business processes is still a major industry concern and efficient solutions remain to be developed that address the following two important issues:

- Semantic unification as the basis for information and knowledge sharing;
- Process co-ordination in large distributed business environments.

This research focuses on the second issue and suggests a solution based on ECP that supports both decision-making processes and collaborative working practices.

The idea behind developing an enterprise modelling and integration framework is that many components/tasks of business process re-engineering projects are similar and common to most businesses. Thus, proven solutions could be captured, standardised, and re-used instead of developing them from scratch each time. Once standardised and accepted, these frameworks can be supported by models and methodologies, leading to time and cost efficiencies. Such standard models once created, could be stored in a case-base repository and then reused by applying intelligent retrieval techniques.

The proposed approach incorporates emerging concepts from two main areas, Business Process Modelling and ECP. The collaborative portals enable members of geographically dispersed teams to discuss any issue associated with the business, remotely. To facilitate this, a graphical process-modelling tool is proposed that allows process models to be designed collaboratively. Regarding the portal, through a user-friendly interface, simultaneous access of every team member to predefined process templates could be provided. In these templates the attributes of the processes, such as cost, time duration, measurements, etc., plus events and responsible units are specified by users. The processes are defined together with their sub-processes and existing interrelationships. In addition, case-based reasoning tools are proposed to assist users in retrieving existing process models from the case base repository that could be adopted to the new requirements of the collaborative environment.

5.3.1 Description of the proposed approach

The proposed approach is presented in [Fig. 5.1]. The input information required is any type of process diagram. Firstly, this information is used to check whether it is necessary to create a new process model. In case the process already exists, it is retrieved from the case base to initiate a discussion among all members of the team concerned. All the participants in the discussion have access to Conference and Graphical Process Modelling tools and the portal services. The Case-based Reasoning tool assists them in identifying the best existing match to specified requirements. When the discussion is completed, the generated process model is added to the case base for future reference and at the same time is sent by email to all concerned parties for final approve. If the generated process model is approved, a workflow is activated automatically. If it is not approved, a new discussion between the team members is initiated until they reach agreement.

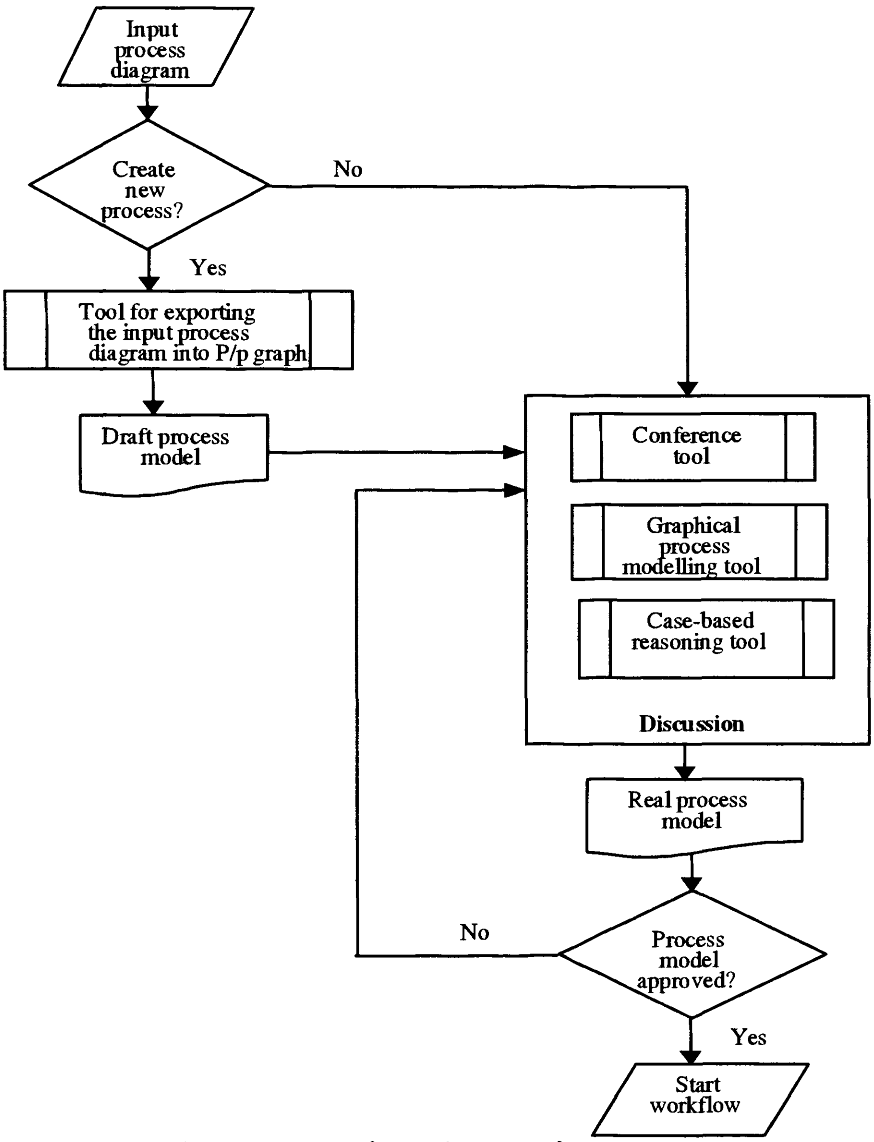


Fig. 5.1 - Algorithm for creating a process model

In case it is necessary to create a new business process, the process diagram, once prepared, is exported into an extended P/p graph so that a draft process model can be created. This draft model can then be analysed by all the members of the team employing Conference, Graphical Process Modelling and Case-based Reasoning tools available on the portal. On completion of this analysis an executable process model is generated and sent automatically to everybody participating in the discussion. The process of approval could involve further discussions until the process model satisfies the requirements of all team members. Finally, a workflow based on the generated process model is implemented.

5.3.2 Case study

The case study concerning the production of the Golf training device prototype, which was described in Chapter 3, will be used to demonstrate the proposed approach.

Case study objective: *Business process modelling using an Enterprise Management System (e.g. PTC Windchill™)*

Selected product: *Golf Training Device (GTD)*

The selected product is a golf training device, assembled from four parts: body, pulley, pulley vee block and squaring bar. The task is to build a prototype of this device employing Rapid Prototyping (RP) technology (SLS DuraForm). The main participants in fulfilling this task are the following three parties:

- the client, ordering the production – "Company X";
- the manufacturer - "Company Z";

- the supplier of materials – "Company Y".

The team that should create/agree of a business process for providing a RP service includes:

- Product engineer from "Company X" who has created the 3D model of the product;
- Project administrator from "Company Z" who co-ordinates all the processes within the company;
- RP project manager who is responsible for the project within "Company Z";
- Material supplier from "Company Y".

The client sends his request for prototyping the GTD to the manufacturer. The project administrator considers the request and then creates a new project for managing the prototyping business process ([Fig. E.1] and [Fig. E.2] in Appendix E) and the GTD product structure ([Fig. E.3] in Appendix E) within the PTC Windchill Enterprise Information Management System (EIMS) ™. The administrator is also responsible for preparing the initial diagrams of the business processes that then will be discussed between all the parties involved. For this case study a Process Chain Diagram (PCD), representing events, activities, documents and responsible units is selected as input for the Graphical Process Modelling tool. It is also possible to use as input, extended Product/process graphs in accordance with the extended P/p methodology proposed in Chapter 3. Examples of possible inputs to the system are the PCD of the Main Business Process shown in [Fig. 3.3] and the P/p graph of the same process in [Fig. 3.5].

The project administrator then triggers the discussion between the project partners by emailing all participants the CAD model of the product and also the references to the product and project data in PTC Windchill ™. At the agreed date and time the discussion commences using the collaboration tool Windows NetMeeting Version 3.01 Microsoft Co. ™ ([Fig. E.11] in Appendix E). All participants load the product and project data from the database. The project administrator starts the Graphical Process Modelling tool and loads three diagrams representing the Main Business Process ([Fig. E.5]), the RP subprocess ([Fig. E.6]) and the Quality check subprocess ([Fig. E.7]), which have been prepared in advance. Since the Graphical Process Modelling tool provides the participants with a shared workspace, all participants can change processes, activities or organisational units and if required even delete or add new activities and attributes. The participants can also send messages or remarks to each other, as shown in [Fig. E.11].

In case a similar process has been designed before and is available in the case-base repository, this process could be retrieved and modified by the project participants using the Graphical Process Modelling tool.

During the discussion it may be required the process diagrams to be changed several times. For example, the project administrator could suggest a new event "Quotation revised" to be added to the process. Also it could be necessary to add other activities such as "Checking received files against the original files", "Checking the RP machine availability" and "Checking for outstanding payments with the customer" before starting the RP subprocess. In addition, RP project manager could suggest quality checks to be added after "Cleaning and post processing", "Joining parts" and "Painting" to the RP subprocess diagram. The product engineer, who represents the client, may propose the activities "Delivery time estimation" and "Process plan revised" to be included in the process diagram to be in position to select the most appropriate manufacturing route for their requirements. The material supplier identifies that the activity "Change material" is not necessarily always required, so he suggested to change the process by adding a new event "Change material required" in the RP subprocess diagram.

The outputs from the Graphical Process Modelling tool are workflow diagrams that represent of the discussed business processes. In this research, these workflow diagrams are created using the PTC Windchill Process Administrator ™. The output of the system consists of workflow templates stored in the PTC Windchill ™ database that could be exported into files with neutral format, such as XML.

At the same time the data from each session is stored on the server in the common workspace and locally on the computer of every participant in the discussion together with the generated business process model. This process model is sent to every member of the discussion group of team members by email for approval or further discussion if necessary. The output of the system can be considered as input information for a workflow system. A workflow can be initiated using this process model ([Fig. E.8]) and then executed ([Fig. E.9]).

5.4 System architecture

The case study presented in the previous section highlighted several problems in implementing the proposed approach by using the PTC Windchill EIMS ™, in particular:

- the initial Process Chain Diagram (PCD) or Product/process graph has to be created manually or using other software, since PTC Windchill EIMS ™ does not provide a proper tool for generating such diagrams;
- the existing process modelling tool in PTC Windchill EIMS ™ is not appropriate for collaborative work, hence a new Graphical Process Modelling tool is required to enable the members of a team to work on the process diagram simultaneously;
- a collaboration tool is required to facilitate communication and visualisation of the shared process diagram between the team members;
- a case-based reasoning tool is not available to enable the retrieval and adaptation of existing models to new requirements;
- a tool is required to allow the exporting of workflow diagrams from the Windchill database into a neutral file format (e.g. XML);
- compatibility and interoperability of the tools listed above is necessary to ensure their proper utilisation.

These problems have to be addressed in order to implement the proposed approach for creating business process models. The existing practice is most stages to be performed manually making the process modelling inefficient. By introducing new tools it would be possible to increase the efficiency in modelling business processes, shorten the time for creating them and improve the quality of the resulting process models. In conclusion, several new tools are required to provide an automated business process modelling: Graphical Process Modelling (GPM) tool, Collaboration tool, Case-based reasoning (CBR) tool and Tool exporting workflow diagrams into XML format.

The proposed tools should become components, an integral part of ECP, and therefore the modelling approach underpin by them is suitable for international collaborative projects involving a significant number of partner companies or for multinational companies executing several projects at the same time. The architecture of ECP that includes these tools is shown in [Fig. 5.2]. The ECP is described only with its server tier (including Portal Services and Server Workspaces) and data tier (databases) for simplicity. The user access tier of the portal could be either via a Web server, or through an API within C, C++, Java or Visual Basic applications.

When a discussion is triggered, all the data exchanged between different teams, for example Team1 (customer), Team 2 (manufacturer) and Team 3 (supplier), is stored in a log file together with the business process model resulting from it. When the discussion finishes this log file (designated as "Process model and Discussion log file" on the diagram) is stored, both on the server and also on the local disk space fo each team member. The GPM tool is employed to create the process model or introduce changes in an existing model by the team in collaborative mode. The process model approval is carried out via email notification. After its approval, a workflow management system takes over the process model execution.

5.4.1 Tool for exporting the input process diagram into a P/p graph

This tool is designed to help those responsible for the creation of the initial business process model. The task of the Project manager is to prepare a graphical representation of the draft process model in advance and share/discuss it with the other team members during collaborative sessions. Two possible inputs, a PCD or UML process diagrams, are considered as a base for creating P/p graphs.

5.4.1.1 Exporting a PCD into a P/p model

Firstly, a mapping between the modelling concepts of a PCD and a P/p graph should be established. [Table 5.1] presents the concepts implemented in these two modelling techniques together with their mapping.

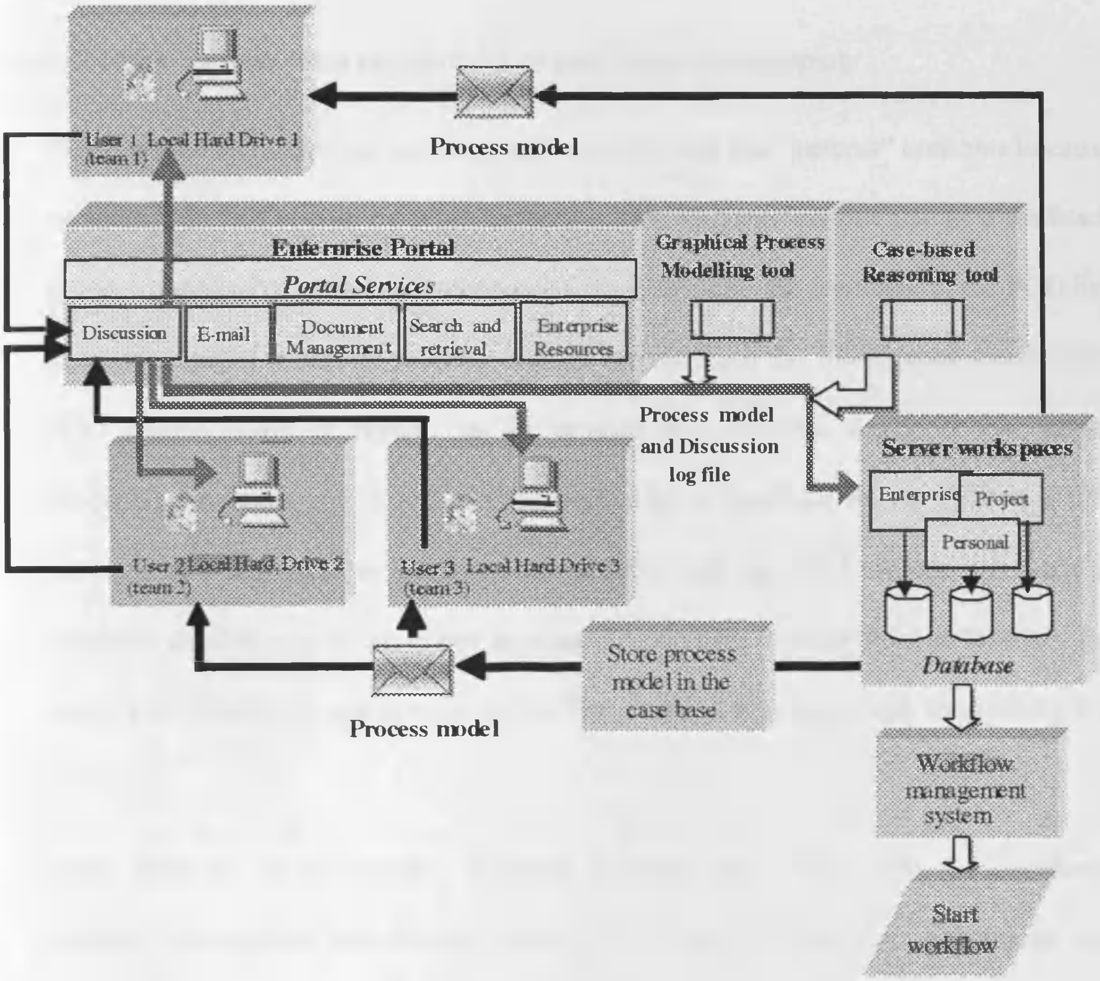


Fig. 5.2 - Proposed system architecture

Concepts in PCD	Concepts in P/p	Mapping exist?
Activity	Process or feedback	Yes
Event	Product or collection or distribution gate	Yes
Document	Process attribute	Yes
Responsible unit	Process attribute	Yes
-	Time	No

Table 5.1 - Mapping of PCD and P/p modelling concepts

Several problems have been encountered in identifying this mapping:

- There is no exact mapping between the "activity" and the "process" concepts because an activity in PCD could be represented not only as a process but also as a feedback in the proposed P/p models. A mechanism to distinguish the feedback in the PCD has to be established. Such mechanism should benefit from the information provided in PCD control flows in regards to the relationships between the input and output products, processes and feedbacks. In particular, a feedback in the PCD is a link between two activities or between an activity and an event, where one activity precedes another one or an event in time. Thus, if the control flow is forward, the activity is considered as a process in the P/p model, if it is backward, the activity is a feedback.

- Also, there is no one-to-one mapping between the "event" and the "product" concepts. To address this problem any event in the PCD that does not require any logical operations, is represented as a "product" in the P/p graph. If the event requires logical operations, such as AND, OR or XOR, then it is regarded as a "collection gate" or "distribution gate" in the P/p graph, depending on the logical operation performed.

- Finally, no mapping is found for the "time" concept in the P/p model.

Taking into account these considerations, an algorithm for exporting the PCD into a P/p model is presented in [Fig. 5.3].

5.4.1.2 Exporting UML process diagram into developed P/p model

A similar method has been used to define a mechanism for exporting UML process diagrams into P/p models. Again, first the mapping between the modelling concepts of these two techniques is established as shown in [Table 5.2].

Concepts in UML	**Concepts in P/p**	**Mapping exist?**
Activity diagram		
Activity	Process	Yes
Signal (Event)	Product	Yes
Forking	Distribution gate	Yes
Joining	Collection gate	Yes
Decision	Distribution gate	Yes
Process diagram		
Process	Process	Yes
Feedback (as "information" resource)	Feedback	Yes
"People" resource	Process attribute "owner" or "agent"	Yes
"Information" resource	Process attribute "document"	Yes
"Physical" resource	Product or Process attribute "agent"	Yes
"Abstract" resource	Process attribute "document"	Yes
-	Time	No

Table 5.2 - The mapping between the modelling concepts of UML and P/p model

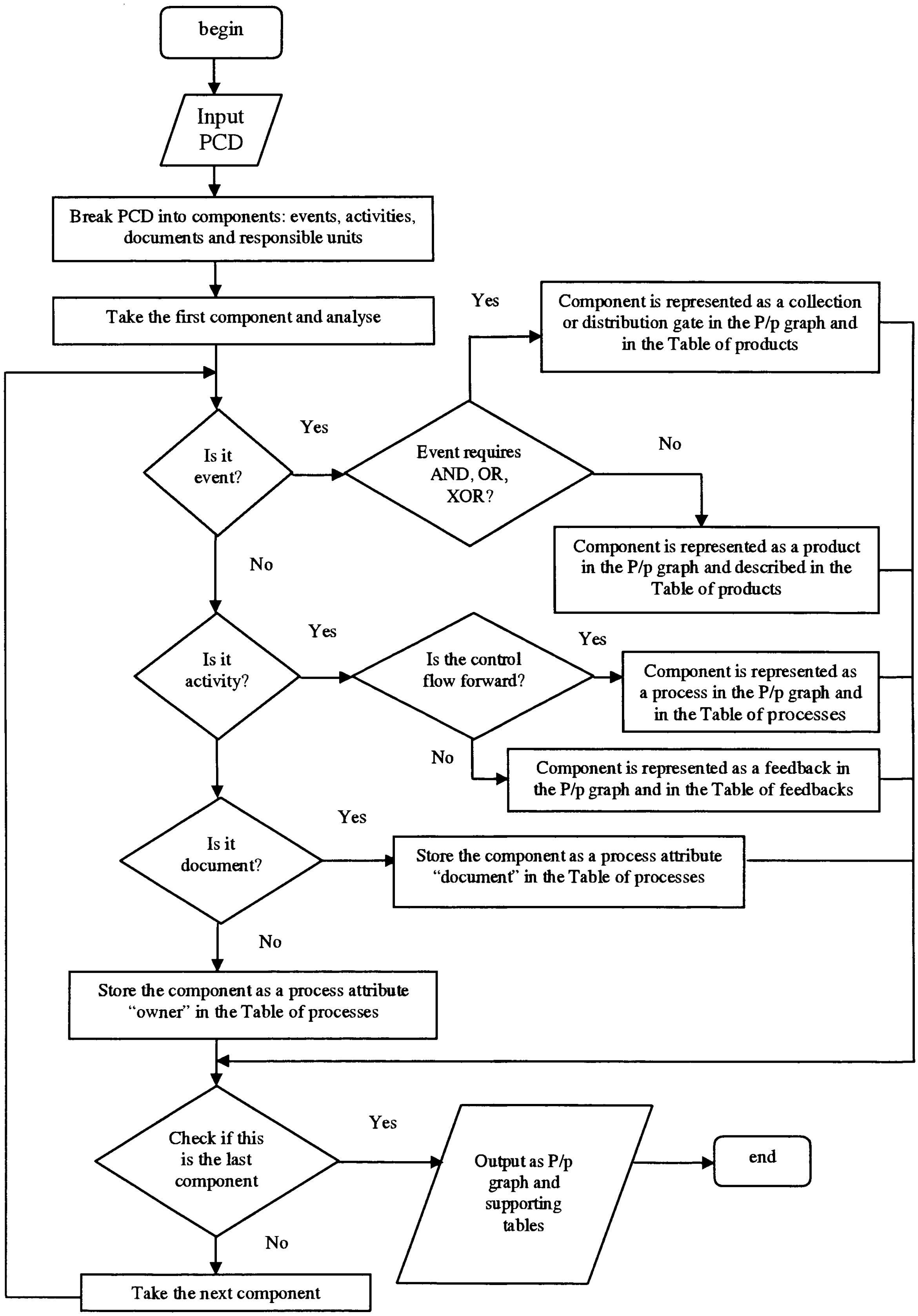


Fig. 5.3 - Algorithm for exporting PCD into a P/p model

The following problems were encountered in identifying this mapping:

- Two UML concepts "joining" and "decision" are mapped to the "distribution gate" concept of P/p models.
- Another two UML concepts, "activity" and "process", relate to the same concept "process" in P/p models. However, since a process consists of a number of activities, the "activity" concept can be considered as a subprocess.
- The same process attribute, "document", in the P/p model relates to two types of resources in UML, "information" and "abstract".
- The UML "people" resource is mapped to two different process attributes in the P/p model – "owner" or "agent". This problem is resolved in the following way: if "people" is a control resource, then it is represented as a process attribute "owner" in the P/p model. In all other cases "people" resource is represented as a process attribute "agent" in the P/p model.
- The UML "physical" resource can be represented either by "product" or "agent" concepts in the P/p model. Therefore, if the "physical" resource represents an input or output resource in the UML process diagram, then it is regarded as a product in the P/p graph. If not, the "physical" resource is considered as a supply resource and represented as a process attribute "agent" in the P/p model.
- Mapping does not exist for the "time" concept in P/p models.

An algorithm for exporting the UML process diagram (considering that the activity diagram is a detailed description of the process in the process diagram) into a P/p model is presented in [Fig. 5.4]. To perform this operation it is required activity diagrams to provide a detailed description of the process.

The methods developed for exporting the PCD or UML models into a P/p model will allow the initial business process model to be generated by employing traditional process modelling techniques. The proposed exporting tool provides good mapping capabilities between the modelling concepts implemented in different process modelling techniques and ensures that no valuable information is lost during the conversion.

5.4.2 Collaboration tool

Collaborative work between globally dispersed teams requires the establishment of communication channels for sharing data. In the proposed system the team members share the process models employing a graphical process modelling tool that enables them to have access to data concurrently. They also can exchange comments in form of messages and annotate models by employing conference features, such as chat, whiteboard, file transfer, audio and videoconferencing.

The collaboration tool discussed in this research is an integral part of the ECP. It is based on the Windows NetMeeting Version 3.01 Microsoft Co. ™ ([Fig. E.11] in Appendix E), which enables globally dispersed product development teams to work together on projects through web-based workspaces. Cross-functional participants from marketing, engineering, procurement, manufacturing, sales and service departments could participate in the product development process in addition to suppliers, manufacturing partners and customers.

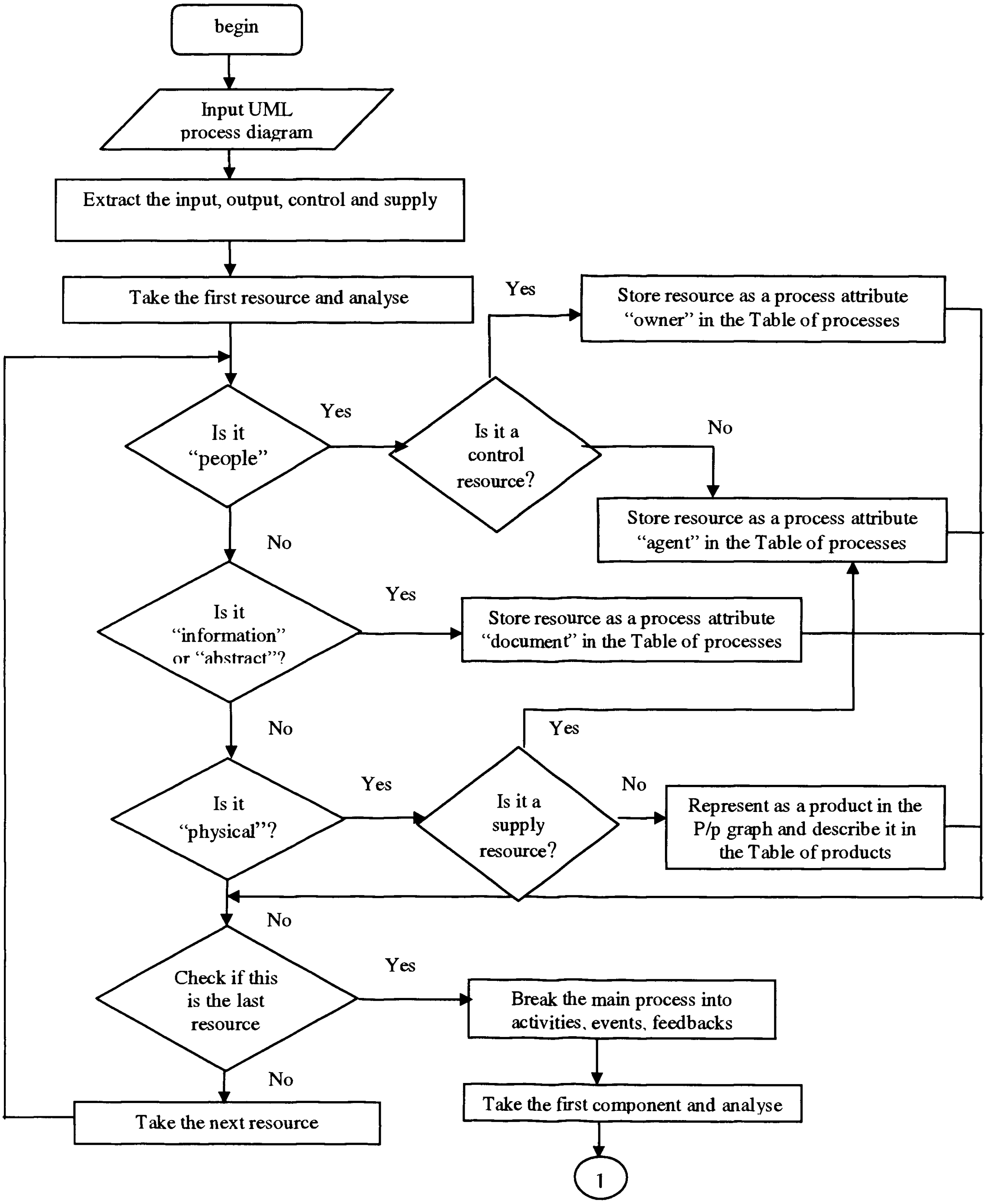


Fig. 5.4 - Algorithm for exporting UML process diagrams into P/p models

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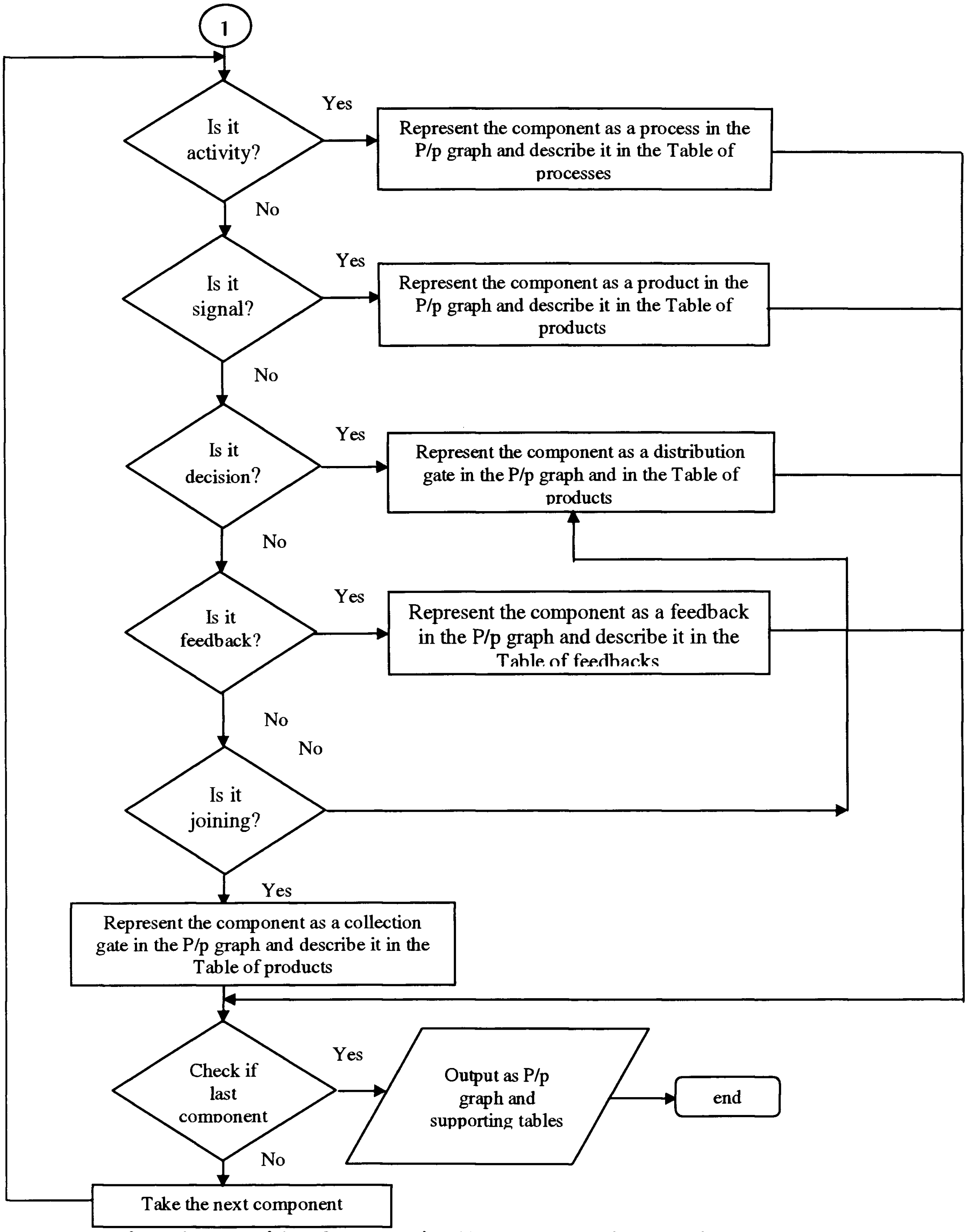


Fig. 5.4 - Algorithm for exporting UML process diagrams into P/p models (continued)

A collaboration tool for business process modelling should possess the following features:

- Simple and secure web access by providing single login and security;
- Intuitive user interface and configurable business process templates;
- Personalised user workspaces;
- Automation and management of key processes including workflow automation tools that enable standard routing and review flows, and execution of complex business processes;
- Collaboration server to ensure synchronous access and provide collaboration services, such as document services, real-time meetings, file exchange, SQL, process models, etc.;
- Multi-users communication and notification;
- Collaboration reporting for capturing and classification of notes created during a given session;
- Shared business process models that could be modified during a session by one participant at a time. During such modification the model is locked to other participants and only afterwards they can view and discuss the introduced change, or make changes of their own.

All these features are provided by the collaboration tool used in this research (see in [Fig. 5.5]).

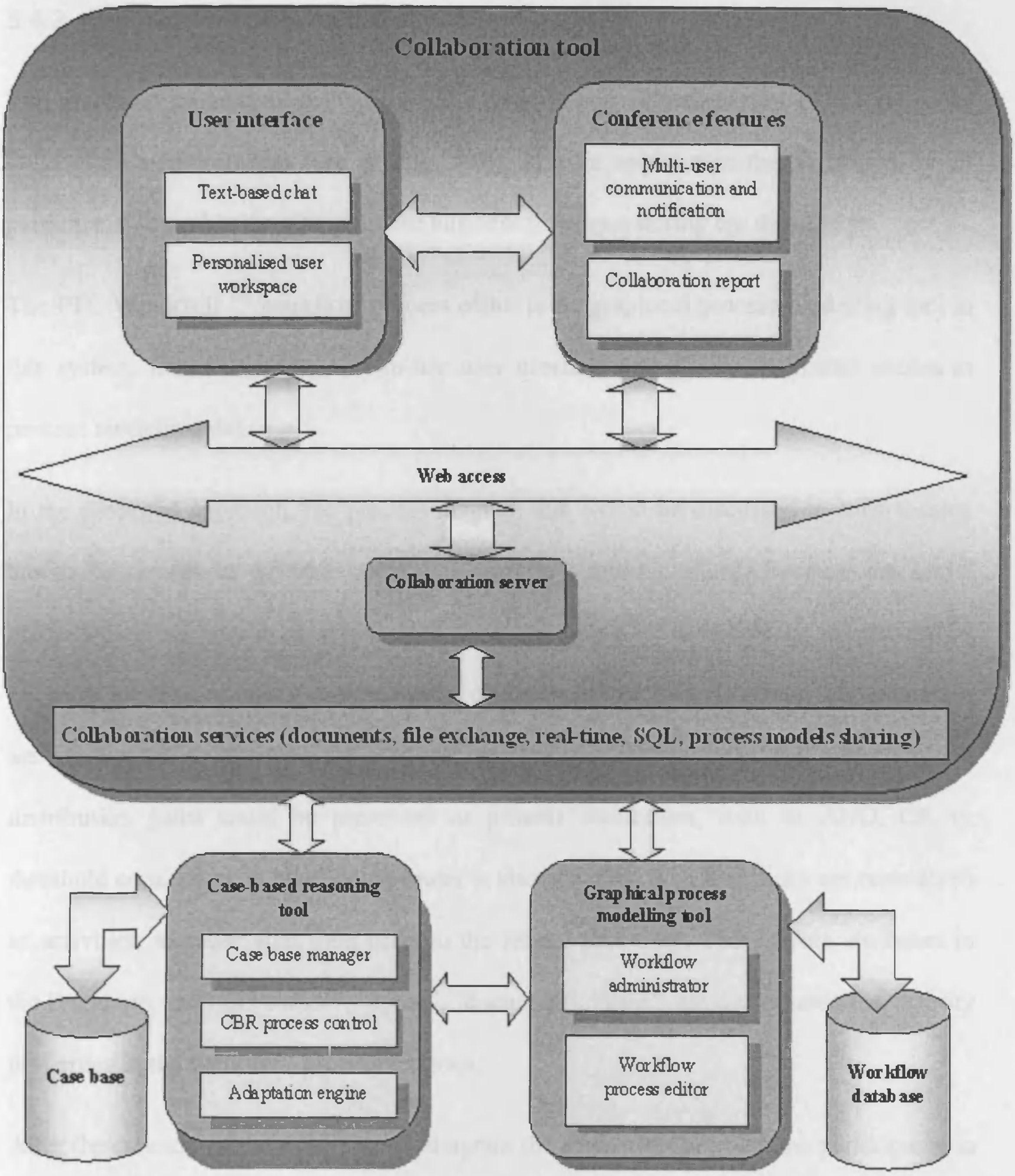


Fig. 5.5 - Collaboration tool architecture

5.4.3 Graphical process modelling tool

The graphical process modelling tool is a very important component of the proposed collaborative environment (see in [Fig. 5.6]). It is an application that is shared by all participants to enable them to visualise business processes during the discussion.

The PTC Windchill ™ workflow process editor is the graphical process modelling tool in this system. It has a simple easy-to-use user interface that allows multi-user access to process modelling data.

In the proposed approach, the process diagram that would be discussed in each session has to be created in advance using this workflow process editor. Because the initial process diagram would be represented as a P/p graph, it is necessary to convert its concepts into the graphical representation of the workflow process editor. The processes are represented as activities, the products are shown as process links, and collection and distribution gates could be presented as process connectors, such as AND, OR or threshold connectors. A conditional router is also provided. The feedbacks are considered as activities, together with their links to the related processes. The process attributes in the P/p graph, such as "owner", "agent", "document", "time", etc. are regarded as activity properties in the workflow process diagram.

After the creation of the draft process diagram the discussion between the participants in the project could be initiated. The graphical process modelling tool is collaboratively applied by the team members to visualise change and discuss the process model until they reach an agreement. The resulting model is saved as a process template and also it is added to the case base for future reference ([Fig. E.5], [Fig. E.6] and [Fig. E.7] in the Appendix).

The architecture of the graphical process modelling tool and its bi-directional links to the collaboration and case-based reasoning tools are presented in [Fig. 5.6]. The workflow process editor and the workflow administrator perform various activities jointly, such as modifying or creating a new business process template and then saving it in the database. The activity properties of the process diagram are stored in the workflow database. The workflow administrator is also engaged in process automation and management.

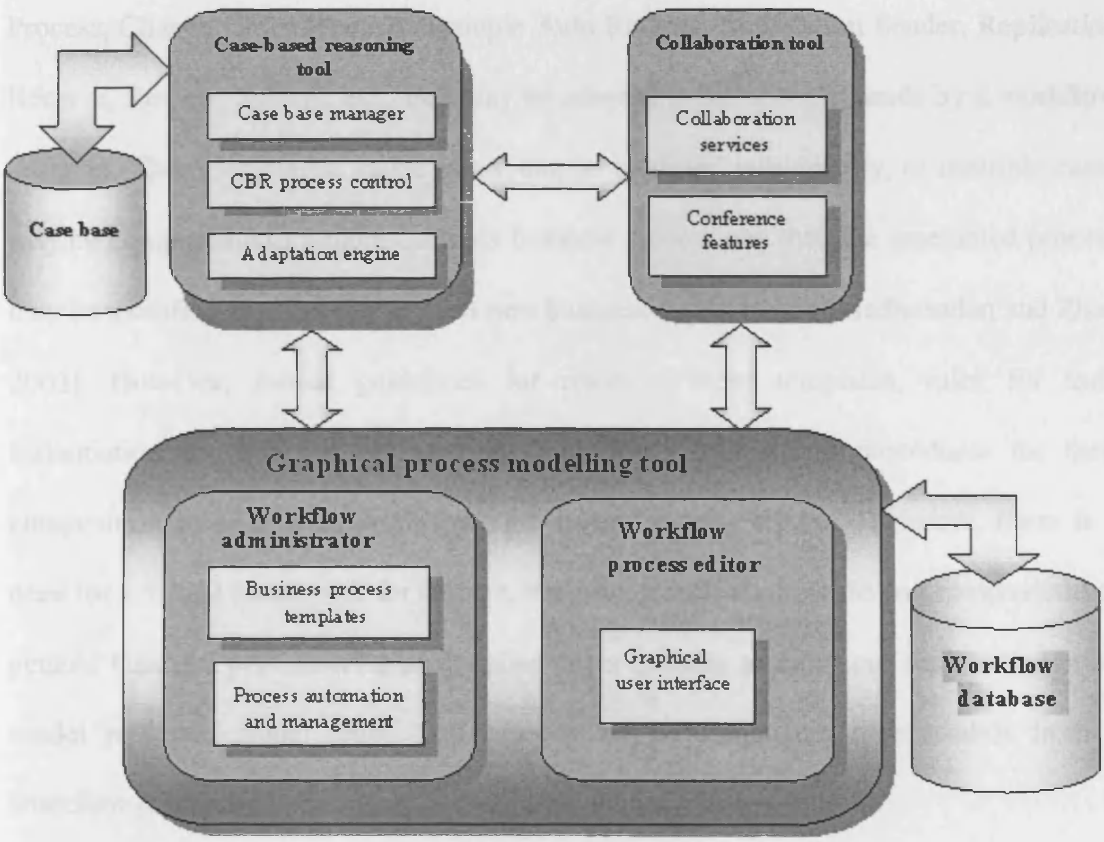


Fig. 5.6 - The graphical process modelling tool architecture

5.4.4 Case-based reasoning tool

The role of the case-based reasoning tool is to enable teams working on process modelling tasks to reuse solutions developed previously, which could be employed partially or fully to solve new problems. This tool is used to select an existing business process model from the case base, which could be utilised as a starting point for developing a new process model.

Commercially available systems, such as PTC Windchill ™, provide basic business process templates, such as Analysis Process, Change Activity Process, Change Request Process, Change Order Process, Example Auto Routing, Replication Sender, Replication Receive, Review, Submit, etc., that may be adopted to the specific needs by a workflow designer. These templates, called cases, can be modified individually, or multiple cases may be composed into a more complex business process and then the assembled process may be modified as necessary to meet new business requirements [Madhusudan and Zhao 2003]. However, formal guidelines for reuse of these templates, rules for their instantiation in an organisation or for their modification, and procedures for their composition into complex workflows are currently non-existent. Therefore, there is a need for a formal framework for storage, retrieval, instantiation, reuse and composition of generic business process templates, called cases in order to carry out such activities as model retrieval, model reuse, and composition of component case models from a workflow repository.

Firstly, the case base of the system has to be created so it can be used during the creation of the process model for case-based reasoning. In this research, the PTC Windchill ™ basic process templates are used as a case base. Besides the existing workflow templates in this case base, several UML basic process patterns adopted by [Eriksson and Penker 2000] are additionally created and stored in there. These UML patterns can be reused in most of the business processes representing basic structures of the process model. The following UML process patterns are added to the Windchill case base:

- Process feedback pattern – evaluates the business process results and base on those results adjusts the process accordingly to achieve the business process goal;
- Action workflow pattern – represents a tool for analysing communication between parties with the purpose of understanding and optimising this communication;
- Basic process structure – provides the basic structure for describing a business process. It shows how to form the business process concept in terms of supplying business resources, goals for the process and the transformation or refinement of input and output resource objects;
- Process layer supply – organises the structure of complex organisations into primary and supporting business processes;
- Time-to-customer – demonstrates how to describe a business with two main processes in order to shorten the lead-time from customer demand to customer satisfaction.

These process patterns adopted by UML are represented as workflow templates by Windchill graphical process editor and stored in the case base. Examples of the Windchill process representation are shown in [Fig. 5.7] – Process feedback pattern and [Fig. 5.8] – Action workflow pattern.

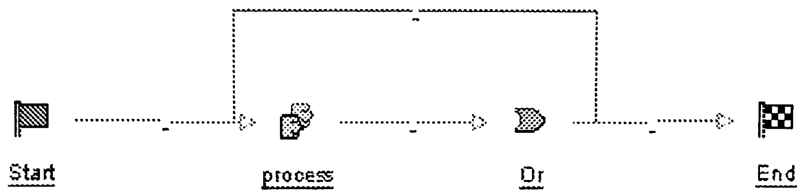


Fig. 5.7 - Process feedback pattern

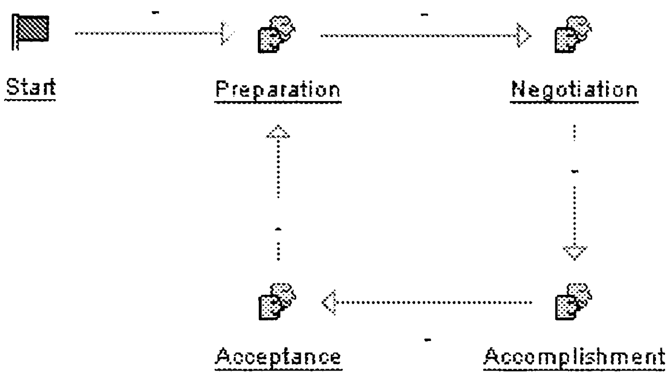


Fig. 5.8 - Action workflow pattern

During the creation task of the process model, the process designer is provided with a high-level description of the business process. He uses the case-based reasoning tool to retrieve past cases that embed "similar" characteristics to the new requirement. After that the process designer will analyse these cases, select relevant cases and composes them into a new solution. This approach is very effective, especially when Business Process Reengineering is required.

The architecture of the case-based reasoning tool is presented in [Fig. 5.9]. The case base manager provides the basic functionality of the CBR tool, including case base indexing, querying and case retrieval functions. The case base consists of an initial set of models, covering the main UML process patterns and the basic PTC Windchill ™ process templates. The CBR process control module provides the link between the process designer, who specifies the queries, and the case base manager that conducts the search for relevant cases. If more than one case matches the search requirements, the cases are ranked in regard to a given matching criterion. The Adaptation engine is used when no similar cases are found or alternatively the retrieved cases need be adapted and verified or multiple cases composed to produce a new solution that is then returned to the process designer. The Graphical process modelling tool is employed to visualise the retrieved cases and then to adopt them interactively to new requirements.

5.4.5 Tool for exporting models into XML format

One of the important applications of the Enterprise Collaborative Portals is the management of the dynamic content of corporate Web sites. Thus, it is important different corporate applications to be able to export the data into many standard file formats, such as HTML, XML and flat text. This applies to business process modelling tools, too. In this research a tool is proposed for exporting process models into XML format that is now one of the most frequently used formatting languages for distributing content over the Internet. Such tool will facilitate the introduction of collaborative working practices allowing project teams to view, copy and save the PTC Windchill ™ workflow template using a standard file format.

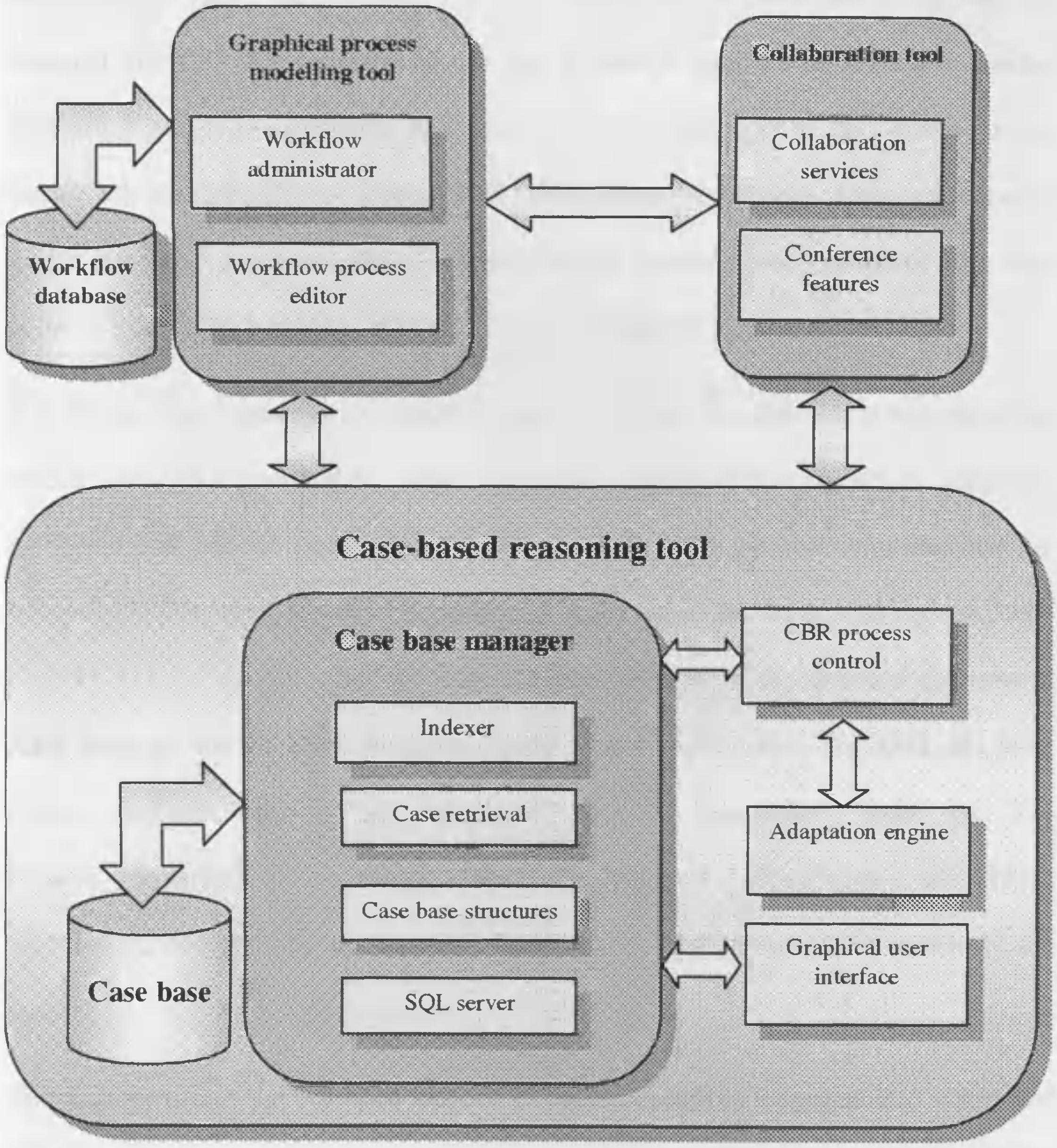


Fig. 5.9 - Case-based reasoning tool architecture

In the PTC Windchill™ environment there are tools for exporting workflow templates into CSV (Comma separate value) file format. Applying these tools, only the templates would be exported. This includes references to underlying objects, such as documents, organisational units, subprocesses etc. The underlying objects themselves are not exported. If a CSV file generated in this way is used to import a template into another database, the underlying objects referenced in the file must exist in the database or the import will fail and errors will appear [PTC 2001]. Thus, the purpose of the tool proposed in this research is to enable project teams to publish process models resulting from their collective efforts by accessing relevant data in the Windchill database.

A CSV file that represents a workflow template contains the different templates of the objects used, such as activities, events, connectors, nodes etc. The objects are separated by "begin-end" blocks. The proposed tool analyses the CSV file, finds and separates the template objects, identifies their meaning and finally associates them with a given XML element. Thus, to carry out this operation the mapping between the structural elements in XML files and the workflow template objects must be established. The XML file must contain elements, such as "activity", "role", "event", "connector", "node" etc. The "node", "connector", etc. objects are related to the graphical representation of the process model while objects such as "activity", "role" and "event" represent the content of the model.

The architecture of the proposed tool for exporting workflow templates into a standard file format (XML) is adapted from [Huang 2002] and is shown in [Fig. 5.10]. The XML export script separates the content to be published from its associated placeholder formatting. The placeholders provide instructions how the contents on the resulting XML page to be formatted properly. The script extracts the content and then it packages it on a single XML page [Huang 2002]. When the content is converted into the XML format, each XML element is filled in with the content of the corresponding placeholder in the database and the placeholder attribute is removed.

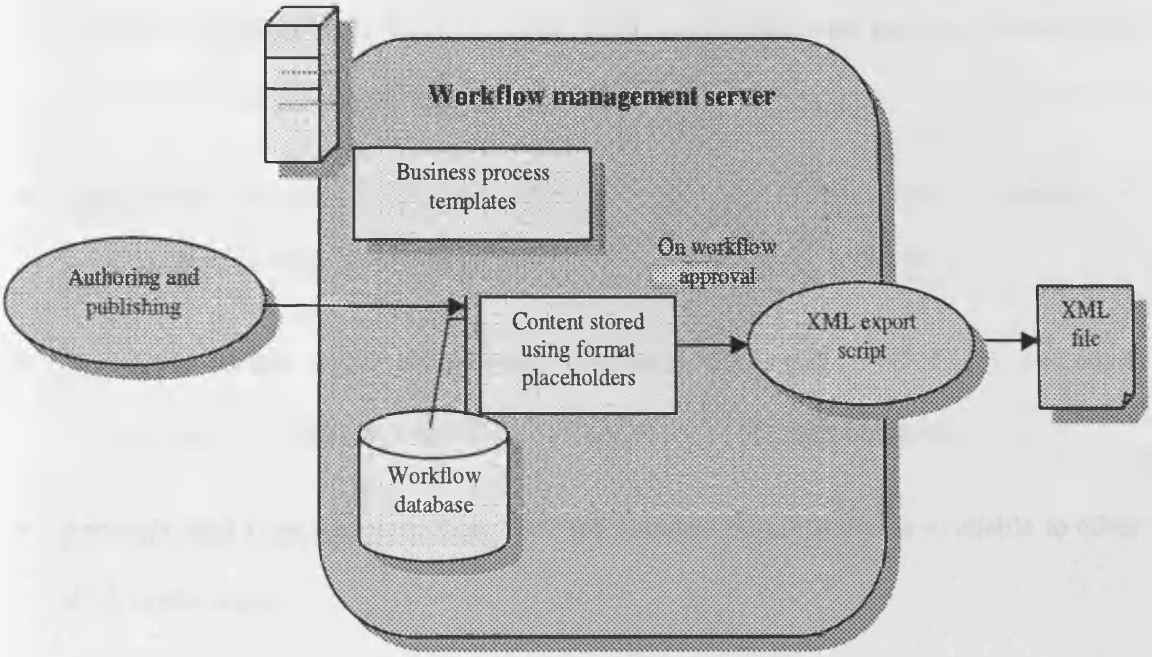


Fig. 5.10 - Exporting tool architecture [Huang2002]

5.4.6 Portal services

The ECP proposed in this research provides a framework for integrating different business applications, such as business process modelling, workflow automation, product visualisation and collaboration, discussion and conference services. It serves also as a mediator between the business applications and the presentation of the information provided by the system.

In particular, the services offered by the portal could be defined as follows:

- **Collaboration:** users of other Web applications can share documents and assign tasks or participate in discussions.
- **Content Management:** users of other Web applications can publish, manage and store content from within those applications.
- **Integration:** services integrated by the portal from third-party systems as portlets can be embedded in Web sites outside the portal.
- **Search:** users can search repositories indexed by the portal on other sites, and other sites and applications can contribute content to a central indexing system.
- **Security and User Information:** user information on the portal is available to other Web applications.

The detailed list of services provided by the proposed portal is presented in [Table 5.3]. Some of the services, including meetings, version control, report building, file manager, user login, user profiling, customisation, system notification, calendar, workflow engine, application integration and enterprise resources, are already provided by the PTC Windchill EIMS ™. Other services, such as collaboration, are provided by the Collaboration tool, described in Section 5.4.2. Additionally, some services, such as channels and the document management and personalisation services, are integrated into the portal as servlets. The portal services interface is based on Java Server Pages (JSP).

The portal architecture is shown in [Fig. 5.11]. It consists of seven layers – Information Storage, Backend Services, Business Applications, Integration, Presentation, Communication and Client.

The **Information Storage layer** provides the databases that underpin the application and services available on the portal.

The **Backend Service layer** provides the necessary infrastructure to support the execution of formal models and procedures, such as Workflow, Security, Version Control and System Log Engines.

The **Business Application layer** provides the functionality that is necessary for business process modelling, workflow automation, product visualisation, collaboration, discussions and conferencing.

The **Integration layer** integrates the available business applications on the portal.

The **Presentation layer** organises the information gathered by the integrator in accordance with the client media.

The **Communication layer** provides WWW services, email and file transfer.

The **Client layer** represents the client platforms and applications within the system.

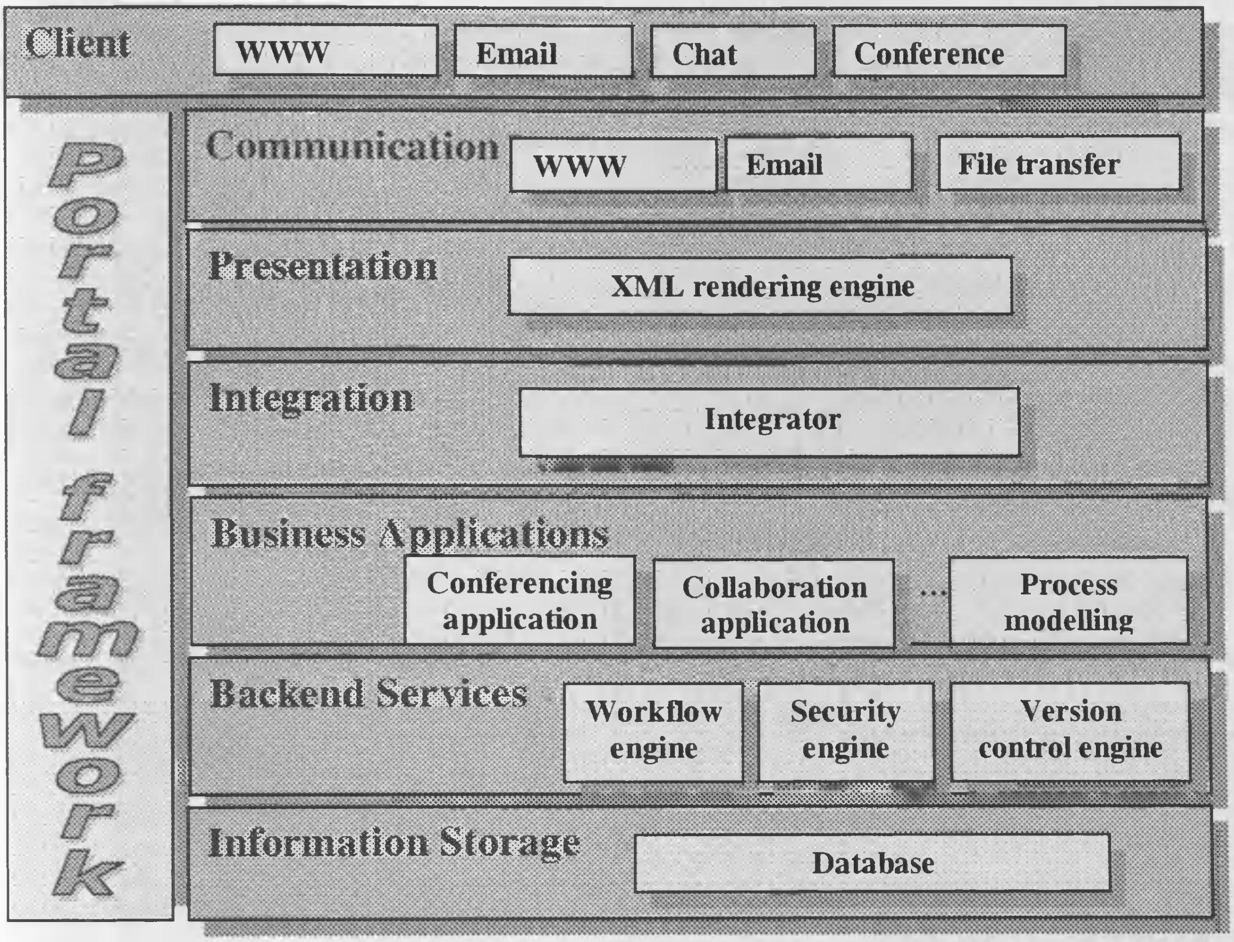


Fig. 5.11 - Enterprise Web Portal architecture

CATEGORIES	
TYPES OF SERVICES	SERVICES
COLLABORATION	EMAIL
	CHAT
	MEETINGS
	MESSAGE BOARD
	VOTE
DOCUMENT MANAGEMENT	VERSION CONTROL
	PICTURE PUBLISHER
	CATALOGUE PUBLISHER
	SLIDE PRESENTATION
	REPORT BUILDING
SEARCH AND RETRIEVAL	FILE MANAGER
PERSONALISATION	USER LOGIN
	CUSTOMISATION
	USER PROFILING
	SYSTEM NOTIFICATION
	CALENDAR
	CALCULATOR
CHANNELS	NEWS
	WEATHER
	STOCK QUOTES
	DICTIONARIES
APPLICATION INTEGRATION	PDM, CAD, PROCESS ADMINISTRATOR, DOCUMENT MANAGER
WORKFLOW ENGINE	PTC WINDCHILL ™
ENTERPRISE RESOURCES	ERP LINK
	DATABASE LINK
	WAREHOUSE LINK

Fig. 5.12 - Services provided by the Enterprise Web Portal

5.5 Summary

The ECP proposed in this chapter addresses the growing need for Internet-based business process modelling tools that enable the design and execution of dynamic workflows. There is a necessity for co-operation between geographically dispersed teams, which requires fast and reliable communication between team members. The algorithm suggested here satisfies this need by employing the ECP environment and services.

In particular, the main contributions of the proposed solution are as follows:

- A case base of standard process models is created, which can be reused by applying case-based reasoning techniques.
- An approach for collaborative creation of business process models is suggested, that also allows existing process models to be reengineered, involving members of geographically dispersed teams.
- A distributed business environment based on the ECP that enables collaborative authoring of dynamic workflows is proposed. The following tools are developed within this environment: a tool for exporting the input process diagram into a P/p graph, a collaboration tool, a graphical process modelling tool, a CBR tool, a tool for exporting the created process model into XML format, Portal services.

The weakness of this solution is that it integrates a range of applications, which makes the system large and complex. Nevertheless, it is easy to use, because it is an Internet-based system that provides standard portal services and enterprise applications. The system was implemented using the PTC Windchill EIMS™, which allowed the proposed approach to be validated.

Chapter 6 - Contributions, Conclusions and Further Work

The aim of this research was to provide collaborative authoring of dynamic business process models in large distributed business environments. This chapter summarises the contributions to this aim and the conclusions reached and proposes areas for further investigation.

6.1 Contributions

The main contribution of this research is the development of a methodology for the collaborative distributed development of dynamic manufacturing workflows. This represents a significant step towards overcoming the problems faced by geographically dispersed teams working on joint projects with regard to the creation of business process models and with respect to communication and co-ordination issues. The specific contributions are summarised below:

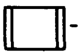
1. A methodology for business process modelling, which provides the required functionality. This is based upon a set of extensions to the P/p methodology [Kaposi and Myers 2001] that address the specific requirements of business process modelling, in particular:

- Feedbacks are incorporated and a proper formalism for representing them is defined.
- Since feedbacks are applied, it is required that products to have two (or more) different time stamps. Thus, time durations, similar to those defined for processes, are introduced for products.

- Each feedback included in the model has a formal definition, graphical notation and attributes that are stored in supporting tables.

- Revised definitions and formal representations of products and processes are introduced.

- New attributes are included in the definitions of the products and processes in order to represent feedbacks.

- New symbols are incorporated in the extended P/p graph, such as $\otimes$ - comparator,  - actuator,  - sensor and 

 - feedback system.

2. A benchmarking methodology for business processes based on the extended P/p methodology and [Spendolini 1992]. The proposed methodology evaluates the quality of the business process and provides comparison with different process scenarios by varying different process attributes. It also identifies the benchmarking factors for business processes – time, cost and quality. The following areas of application of the proposed methodology are outlined:

- As a process simulation tool when it is necessary to predict the outcome of a radical change to the process and to recognise the dynamic nature of the process.

- As a comprehensive instrument for operational and quality management.

- For measuring the business process performance, as verified by the benchmarking results.

- For comparison of the quantitative and qualitative results of the benchmarking factors in three different dimensions:

✓ for the same business process by varying some process attributes, which will lead to optimisation of the process model (internal benchmarking);

✓ for the same business process modelled by applying different methodologies, which will lead to evaluation of the quality of the process modelling methodologies (internal or generic benchmarking);

✓ for two business processes in different environments and conditions (functional or competitive benchmarking).

3. A case base of standard process models, which can be reused by applying case-based reasoning techniques. The case base consists of basic UML process patterns represented as extended P/p graphs according to the extended P/p methodology.

4. An approach for collaborative creation of business process models, as well as re-engineering of existing process models, involving members of geographically dispersed teams. The proposed algorithm satisfies the need for fast and reliable communication between the team members by employing the Enterprise Collaborative Portal environment and services.

5. A distributed business environment based on the Enterprise Collaborative Portal that enables collaborative authoring of dynamic workflows. The following tools have been developed to facilitate the design of the new process model and subsequently to generate a workflow to validate the model created:

- Tool for exporting the input process diagram into a Product/process graph
- Collaboration tool
- Graphical process modelling tool

- Case-based reasoning tool
- Tool for exporting the created process model into XML format
- Portal services

6.2 Conclusions

- Existing process modelling tools have a number of deficiencies. Most of them do not focus on resource management and tend to produce non-executable models. A new methodology is therefore required for developing richer models, encompassing all aspects of enterprise modelling.
- There are no solutions currently available that address the process modelling and co-ordination issues of dynamic workflows and could support geographically dispersed teams. Therefore, an environment enabling collaborative work between globally distributed corporate partners is required.
- The extended P/p methodology developed in this research overcomes many of the basic deficiencies of the existing process modelling techniques. In particular in comparison with the existing P/p methodology and with UML, it introduces feedbacks in the P/p model and provides a representation of the whole business process, together with its subprocesses. The proposed approach proved to be more suitable for solving business modelling tasks and process-oriented problems.
- The proposed benchmarking methodology proved to be comparable to existing benchmarking methods. It is suitable for application in the business domain. In fact, this methodology provides a good basis for measuring the business process

performance, as verified by the benchmarking results. It evaluates the quality of the business process and provides comparison with different process scenarios by varying different process attributes. Therefore, it can lead to reduction in the investment costs related to business process identification, analysis and modelling. Also, it provides the ability to predict the outcome of a radical change in the process and to recognise the dynamic nature of the process, as well as assist the organisation in the continuous process improvement cycle.

- The algorithm for creating a richer process model satisfies the need for co-operation and co-ordination between geographically dispersed teams by employing the Enterprise Collaborative Portal environment and services and the extended P/p methodology introduced in this research.
- The proposed system aims to satisfy the growing need for collaborative business process modelling tools enabling co-ordination of dynamic workflows. It has demonstrated its ability to facilitate the creation of a new business process model, as well as re-engineering of an existing process. The collaborative authoring of dynamic process models and subsequent generation of workflows to validate them is provided by the architecture of the system, including a graphical process modelling tool, a case-based reasoning tool, a collaboration tool, exporting tools and portal services.

6.3 Further work

With regard to the extended P/p methodology, a possible research direction is the development of a process modelling tool, comprising all the aspects of the extended P/p model with feedbacks. Since the P/p graph is a tool for modelling systems, especially business processes, a graphical process modelling tool can be created to satisfy the need for a software package providing a graphical representation for business process models. This tool would employ the concepts of the extended P/p methodology, based on its formal model and graph representation. The information concerning the attributes of the products, processes and feedbacks could be stored as supporting tables in a database.

With regard to the proposed benchmarking methodology, there is opportunity for further research to extend the existing method for all types of organisational units involved in the enterprise and their processes. In this research a benchmarking is conducted only for the same business process by varying some process attributes, which will lead to optimisation of the process model (internal benchmarking). Therefore, another possible research direction is to compare the quantitative and qualitative results of the benchmarking factors for the same business process developed by applying different methodologies (internal or generic benchmarking) or for two business processes in different environments and conditions (functional or competitive benchmarking).

With respect to the algorithm for collaborative authoring of dynamic process models, there is a need to refine this algorithm in accordance with the principles of Concurrent Engineering, which will lead to more efficient use of the current resources and reduction of the investment costs related to the business processes involved.

Another important issue is the integrated Internet-based architecture of the proposed system, which is very complex and large. The exporting tools in this research are only specified as algorithms; therefore there is opportunity for development of these tools to reflect the specified activities. The case-based reasoning tool is currently based on the PTC Windchill EIMS™ workflow database, which is enriched with process templates representing the basic UML process patterns. Therefore, the case base can be enriched and reorganised and retrieval and adaptation techniques to be refined. Another possibility for further development is to add new portal services to facilitate the work of the project team members.

Appendix A - P/p definitions, formal representation and tables of products, processes, feedbacks and their attributes

A.1 Formal representation of a product [Kaposi and Myers 2001]

"Product P is modelled as a black box by the pair: $P_B=(E_{BP},R_{BP})$,

where E_{BP} is the finite set of attribute measures, characterising the product P as a black box (including a zero valued duration attribute, often omitted for conciseness),

R_{BP} is the finite set of interrelations on E_{BP}, which includes:

r_p – the "co-attribute" interrelation, assuring referential cohesion, stating that all measures in the set E_{BP} belong to the same referent,

t_p – the "time stamp" interrelation over attribute measures in the set E_{BP}, assuring temporal cohesion and identifying the real time instant when the attribute measures are valid,

and BP is a suffix designating black box representation of product P (often omitted for conciseness)."

A.2 Formal representation of a process [Kaposi and Myers 2001]

"Process p is modelled as a black box by the pair: $\mathbf{p_B=(E_{BP},R_{BP})}$,

where E_{BP} is the finite set of attributes that characterise the process p as a black box, including

∂**t** - the duration of the process,

D={D_1,D_2,...,D_n} - the "conformance attribute", setting the bounds of the value of each of the **n** attributes of the input, thus defining the domain of input products on which **p** can act,

$\pi=\{\pi_1, \pi_2,..., \pi_m\}$, the "transformation attribute": the set of function defined over the attribute measure set of the input product, each function generating one of the m attribute measures of the output product,

F - the Boolean status parameter, indicating the availability or otherwise of p at the instant of arrival of the input,

Ω - the nominal measure of the process owner of the process (if man-made),

C - the cost of executing the process, a monetary measure in £ sterling, say, of the resources absorbed by the process,

R_{BP} is the finite set of relations over E_{BP} including

r_c - the "co-attribute interrelation" over all elements of E_{BP} asserting that the attributes belong to the same process,

r_t (or t) is the "time stamp" interrelation over all elements of E_{BP}, stipulating the time instant when the attribute measures are valid, and BP is a suffix designating black box representation of process **p** (frequently curtailed)."

A.3 Formal representation of a feedback

Feedback F is modelled as a black box by the pair: $F_B=(E_{BP},R_{BP})$,Where E_{BP} is the finite set of attributes that characterise the feedback F as a black box, including

> ∂t - the duration of the feedback process,
>
> $D=\{D_1,D_2,...,D_n\}$ - the "conformance attribute", setting the bounds of the value of each of the attributes of the input, thus defining the domain of input products on which **F** can act,
>
> $\pi=\{\pi_1, \pi_2,..., \pi_m\}$ - the "transformation attribute": the set of functions defined over the attribute measure set of the input product, each function generating one of the m attribute measures of the output product,
>
> FS - the Boolean status parameter, indicating the availability or otherwise of **F** at the instant of arrival of the input,
>
> C - the cost of executing the process, a monetary measure in £ sterling, say, of the resources absorbed by the feedback process,
>
> n – integer number, representing the feedback iterations,

A – string parameter, representing the actuator,

S - string parameter, representing the sensor,

⊗ - string parameter, representing the comparator,

R_{BP} is the finite set of relations over E_{BP} including

r_c - the "co-attribute interrelation" over all elements of E_{BP} asserting that the attributes belong to the same feedback,

$TS_{BP} = \{T_{BP}, \partial t\} = \{\{t_B^1, t_B^2, \ldots, t_B^n\}, \partial t\}$ - the time set, consisting of:

T_{BP} - the set of time stamps at which the input product arrives on every iteration of the feedback, when the attribute measures are valid,

∂t - the time duration of the input product,

and BP is a suffix designating black box representation of feedback **F** (frequently omitted).

A.4 Tables of products, processes, feedbacks and their attributes

Product	Description	Collection (c) or distribution (d) gate	Class of product	Graphical symbol
P_1	Customer inquiry		soft	- - - -►
P_2	Quotation ready/revised		hard	——►
P_3	Customer response received	d(P_3',P_3'', P_3''')	hard	——►
P_3'	No response from the customer		hard	——►
P_3''	Modification requirements		hard	——►
P_3'''	Quotation accepted, order and files received		hard	——►
P_5	Files checked	d(P_5', P_5'')	hard	——►
P_5'	Files match		hard	——►
P_5''	Files don't match		hard	——►
P_6	Revise the quotation?	d(P_6', P_6'')	hard	——►
P_6'	Yes		hard	——►
P_6''	No		hard	——►
P_7	Requirements for revision	c(P_3'', P_6')	hard	——►
P_9	Check the machines	c(P_5', P_6'')	hard	——►
P_{10}	RP machines checked	d(P_{10}', P_{10}'')	hard	——►
P_{10}'	RP machines not available		hard	——►
P_{10}''	RP machines available		hard	——►
P_{11}	Time estimated		hard	——►
P_{12}	Outstanding payments checked	d(P_{12}', P_{12}'')	hard	——►
P_{12}'	Yes		hard	——►
P_{12}''	No		hard	——►
P_{13}	Need to inform the customer	c(P_{11}, P_{12}'')	hard	——►
P_{14}	Process plan		hard	——►
P_{15}	Prototype finished		hard	——►
P_{16}	Quality control finished	d(P_{16}', P_{16}'')	hard	——►
P_{16}'	Quality satisfactory		hard	——►
P_{16}''	Quality unsatisfactory		hard	——►
P_{17}	Project report completed		hard	——►
P_{18}	Customer order completed		hard	——►
P_{19}	Customer informed		hard	——►
P_{20}	Customer response received	d(P_{20}', P_{20}'')	hard	——►
P_{20}'	Process plan accepted		hard	——►
P_{20}''	No order		hard	——►
P_{21}	Process plan accepted	c(P_{14}, P_{20}')	hard	——►
P_{22}	Process plan revised		hard	——►
P_{23}	Inform customer		hard	——►

Table A.1 - The products of the Main Business Process

Process	Description	Owner	Input product	Output product	Document	Class of process	Graphical symbol
p_1	Prepare/revise a quotation	Project administration	P_1	P_2	CAD file, cost sheets	soft	
p_2	Send a quotation to the customer	Project administration	P_8	P_3	Quotation	hard	
p_3	Check the received files against the original files	Project administration	P_3'''	P_5	Quotation	hard	
p_4	Check if revision of the quotation is necessary	Project administration	P_7	P_6	-	hard	
p_5	Checking the RP machines availability	Project administration	P_9	P_{10}	-	hard	
p_6	New delivery time estimated	Project administration	P_{10}'	P_{11}	-	hard	
p_7	Checking for outstanding payments with the customer	Project administration	P_{10}''	P_{12}	-	hard	
p_8	Inform customer	Project administration	P_{13}	P_{23}	-	hard	
p_9	Start RP project	Project administration	P_{12}''	P_{14}	-	hard	
p_{10}	Prototyping	RP project manager	P_{21}	P_{15}	STL file, drawings, cost sheets, job sheets	hard	
p_{11}	Quality control	Quality manager	P_{15}	P_{16}	Technical requirements, drawings, sketches	hard	
p_{12}	Project report	RP project manager	P_{16}'	P_{17}	Quality control document	hard	
p_{13}	Delivery and invoice	Project administration	P_{17}	P_{18}	Delivery and invoice	hard	
p_{14}	Process plan revised, informing customer	RP project manager and project administration	P_{16}''	P_{22}	-	hard	

p_{15}	Customer response	Project administration	P_8"	P_3	Revised process plan and related documents	hard	
p_{17}	No order	Project administration	P_3'	P_{20}"	-	hard	

Table A.2 - The processes in the Main Business Process

Product type code	**Product type name**		
P_1	Customer inquiry		
Attribute code	**Attribute name**	**Value**	**Dimension**
a_1^1	Customer name	cn	String
a_1^2	Contact person	cp	String
a_1^3	E-mail	e	String
a_1^4	Address	a	String
a_1^5	Telephone	t	Positive integer
a_1^6	Product required	p	String
a_1^7	Quantity	q	Positive integer
a_1^8	Date of inquiry	id	String
a_1^9	Required delivery date	dd	String
a_1^{10}	Expected price	c	Positive integer
Relation code	**Relation name**	**Relation**	
t_1	Time stamp	$r(t_1)$	
r_{c1}	Co-attribute relation	$r_c(a_1^1, a_1^2, \ldots, a_1^{10})$	

Table A.3 - Product P_1 with its attributes

Process type code	**Process type name**		
p_1	Preparing a quotation		
Attribute code	**Attribute name**	**Value**	**Dimension**
a_1^1	Domain	D	Information – sent by e-mail, post, fax or phone
a_1^2	Transfer function	f	$P_2=f(P_1)$
a_1^3	Status	s	**{FREE, BUSY}**
a_1^4	Duration	∂t	Time difference
a_1^5	Owner	Ω	String
a_1^6	Agent	a	String
a_1^7	Cost	c	Positive integer
Relation code	**Relation name**	**Relation**	
t_1	Time-stamp	$r(t_1)$	
r_{c1}	Co-attribute relation	$r_c(a_1^1, a_1^2, \ldots, a_1^7)$	
Input product: P_1			
Output product: P_2			

Table A.4 - Process p_1 with its attributes

Product	**Description**	**Collection (c) or distribution (d) gate**	**Class of product**	**Graphical symbol**
P_1	Customer inquiry		soft	- - - -▶
P_2	Quotation ready/revised		hard	⟶
P_3	Customer response received	d(P_3', P_3'', P_3''')	hard	⟶
P_3'	No response from the customer		hard	⟶
P_3''	Modification requirements		hard	⟶
P_3'''	Quotation accepted, order and files received		hard	⟶
P_4	Customer requirements		hard	⟶
P_5	Files checked	d(P_5', P_5'')	hard	⟶
P_5'	Files match		hard	⟶
P_5''	Files don't match		hard	⟶
P_6	Revise the quotation?	d(P_6', P_6'')	hard	⟶
P_6'	Yes		hard	⟶

P_6''	No		hard	→
P_7	Requirements for revision	c(P_3'', P_6')	hard	→
P_9	Check the machines	c(P_5', P_6'')	hard	→
P_{10}	RP machines checked	d(P_{10}', P_{10}'')	hard	→
P_{10}'	RP machines not available		hard	→
P_{10}''	RP machines available		hard	→
P_{11}	Time estimated		hard	→
P_{12}	Outstanding payments checked	d(P_{12}', P_{12}'')	hard	→
P_{12}'	Yes		hard	→
P_{12}''	No		hard	→
P_{13}	Need to inform the customer	c(P_{11}, P_{12}'')	hard	→
P_{14}	Process plan		hard	→
P_{15}	Prototype finished		hard	→
P_{16}	Quality control finished	d(P_{16}', P_{16}'')	hard	→
P_{16}'	Quality satisfactory		hard	→
P_{16}''	Quality unsatisfactory		hard	→
P_{17}	Project report completed		hard	→
P_{18}	Customer order completed		hard	→
P_{19}	Customer informed		hard	→
P_{20}	Customer response received	d(P_{20}', P_{20}'')	hard	→
P_{20}'	Process plan accepted		hard	→
P_{20}''	No order		hard	→
P_{21}	Process plan accepted	c(P_{14}, P_{20}')	hard	→
P_{22}	Process plan revised		hard	→
P_{23}	Inform customer		hard	→
P_{21}'	Process plan after actuation		hard	→
P_{25}	Customer response analysed		hard	→

Table A.5 - Products in the extended P/p graph of the Main Business Process

Feedback	**Description**	**Input**	**Output**	**Compa-rator**	**Actuator**	**Sensor**	**Goal**
F_1	Customer feedback for the quotation	P_1	P_3'''	Project administrator	Price, quality, time	Customer	To address customer requirements
F_2	Customer feedback for the process plan	P_{14}	P_{20}	RP project manager	Quality, time	Customer	To optimise the process plan

Table A.6 - Feedbacks in the extended P/p graph

Product type code	Product type name		
P_1	Customer inquiry		
Attribute code	**Attribute name**	**Value**	**Dimension**
a_1^1	Customer name	cn	String
a_1^2	Contact person	cp	String
a_1^3	E-mail	e	String
a_1^4	Address	a	String
a_1^5	Telephone	t	Positive integer
a_1^6	Product required	p	String
a_1^7	Quantity	q	Positive integer
a_1^8	Date of inquiry	id	String
a_1^9	Required delivery date	dd	String
a_1^{10}	Expected price	dd	String
a_1^{11}	Set of time stamps	T_{BP}	$T_{BP} = \{t_B^1, t_B^2, ..., t_B^n\}$
a_1^{12}	Number of feedback iterations	n	Positive integer
Relation code	**Relation name**	**Relation**	
t_1	Time stamp	$r(t_1)$	
r_{c1}	Co-attribute relation	$r_c(a_1^1, a_1^2, ..., a_1^{12})$	

Table A.7 - Product with its attributes in the developed P/p graph

Process type code	Process type name		
p_1	Preparing a quotation		
Attribute code	**Attribute name**	**Value**	**Dimension**
a_1^1	Domain	D	Information – sent by e-mail, post, fax or phone
a_1^2	Transfer function	f	$P_2 = f(P_1)$
a_1^3	Status	s	{free, busy}
a_1^4	Duration	∂t	Time difference
a_1^5	Owner	Ω	String
a_1^6	Agent	a	String
a_1^7	Cost	c	Positive integer
a_1^8	Feedback status	FS	Boolean, {Yes,No}
a_1^9	Number of feedback iterations	n	Positive integer
Relation code	**Relation name**	**Relation**	
T_{BP}	Set of time-stamps of the input product on every feedback iteration	$r(T_{BP})$, $T_{BP} = \{t_B^1, t_B^2, ..., t_B^n\}$	
r_{c1}	Co-attribute relation	$r_c(a_1^1, a_1^2, ..., a_1^9)$	
Input product: P_1			
Output product: P_2			

Table A.8 - Process with its attributes in the developed P/p graph

Feedback code	**Feedback name**		
F_1	Customer feedback for the quotation		
Attribute code	**Attribute name**	**Value**	**Dimension**
a_1^1	Domain	D	Information – sent by e-mail, post, fax or phone
a_1^2	Transfer function	f	$P_3'''=f(P_1)$
a_1^3	Feedback status	FS	Boolean, {free, busy}
a_1^4	Cost	c	Positive integer
a_1^5	Number of iterations	n	Positive integer
a_1^6	Actuator	A	String
a_1^7	Sensor	S	String
a_1^8	Comparator	⊗	String
a_1^9	Duration	∂t	Time difference
Relation code	**Relation name**	**Relation**	
T_{BP}	Set of time-stamps of the input product on every feedback iteration	$r(T_{BP})$, $T_{BP}=\{t_B^1,t_B^2,...,t_B^n\}$	
r_{c1}	Co-attribute relation	$r_c(a_1^1,a_1^2,...,a_1^9)$	
Input product: P_1			
Output product: P_3'''			

Table A.9 - Feedback with its attributes in the developed P/p graph

Appendix B - UML basics and UML diagrams for the subprocesses

B.1 UML business model

The UML business model consists of:

- **Views.** A business model is illustrated by a number of different views, each of which captures information about one or more specific aspects of the business. A view is an abstraction from a specific point of view, omitting the irrelevant details. Multiple views are necessary to separate purposes and perspectives in a controlled way, without losing important information about the business.
- **Diagrams.** Each view consists of a number of diagrams, each of which shows a specific part of the business structure or a specific business situation. Several diagrams are necessary to visualise a single view of the business model, since each type of diagram has a different purpose and expresses one important aspect or mechanism within the business model view. A diagram can show a structure (e.g. the organisation of the business) or some dynamic collaboration (a number of objects and their interaction). The diagrams contain and express the objects, processes, rules, goals, and visions defined in the business situation.
- **Object and Processes**. Concepts are related in the diagrams through the use of different objects and processes. The objects are the "things" in the business; they may be physical, such as people, machines, products, and material, or more abstract, such

as debts, instructions, and services. Objects can also represent other objects by containing information about other things in the business. Processes are functions in the business that consume, refine, or use objects to affect or produce other objects.

B.2 UML diagrams

UML has nine predefined diagrams:

- **Class diagram.** Describes the structure of a system. The structures are built from classes and relationships. The classes can represent and structure information, products, documents or organisations.
- **Object diagram.** Expresses possible object combinations of a specific class diagram. It is typically used to exemplify a class diagram.
- **Statechart diagram.** Expresses possible states of a class (or a system).
- **Activity diagram.** Describes activities and actions taking place in a system.
- **Sequence diagram**. Shows one or several sequences of messages sent among a set of objects.
- **Collaboration diagram.** Describes a complete collaboration among a set of objects.
- **Use-case diagram.** Illustrates the relationships between use cases. Each use case, typically defined in plain text, describes a part of the total system functionality.
- **Component diagram.** A special case of the class diagram used to describe components within a software system.

- **Deployment diagram.** A special case of the class diagram used to describe hardware within a software system.

These diagrams capture the three important aspects of the systems: structure, behaviour and functionality. UML also provides three mechanisms for extending the approach to apply to the particular requirements of the modeller:

- **Stereotype**. An extension of the vocabulary of the UML, which allows the creation of new building blocks specific to a problem from existing blocks [Booch 1998]. Stereotypes may have their own icons.

- **Tagged value (property).** An extension of the properties of the UML element, which allows the creation of new information in that element's specification [Booch 1998].

- **Constraint.** An extension of the semantics of a UML element that enables new rules to be added or existing ones modified [Booch 1998].

According to [Eriksson and Penker 2000] a business process has an explicit goal, a set of input objects and a set of output objects. The input objects are resources that are transformed or consumed as part of the process, such as a raw material in a manufacturing process. The input objects also can be refined by the process, in which case the process adds value to them, so that the value of the output of the process is larger than the input. The output objects represent the accomplishment of goals and are the primary result of the process, such as a finished product in a manufacturing process. The output object is also a resource. An output object can be a completely new object created during the processes or it can be a transformed input object. The transformations made by the process can be physical, logical, transactional or informational.

The process interacts during its execution with resource objects other than the input and output objects, that are very important as well. These objects carry information required by the process or they are resources responsible for executing the activities in the process, such as people or machines. For example, in a manufacturing process people operate the machines that transform the raw material into a finished product.

The Eriksson-Penker Business Extensions use these three techniques to customise

UML for real-life business modelling. They provide symbols for modelling the processes, resources, rules and goals of a business system.

The business processes are the active part of the business. They describe the functions of the business and involve resources that are used, transformed or produced. A business process is an abstraction that shows the co-operation between resources and the transformation of resources in the business. Therefore, to summarise, a business process [Eriksson and Penker 2000]:

- Has a goal;
- Has a specific input;
- Has specific output;
- Uses resources;
- Has a number of activities that are performed in some order, depending on conditions and events that occur during the execution of the process. The activities within the process can be seen as subprocesses;

- Affects more than one organisational unit. It is horizontal rather than vertical in regard to the traditional organisation of the business;
- Creates value to some kind of customer. The customer can be either internal or external to the business.

B.3 UML tagged values for Eriksson - Penker Business extensions:

- **Goal.** A textual value that describes the goal of the process if a goal object is not explicitly attached to it.
- **Purpose.** A textual value that informally describes the purpose of the process; for example what the process does and, in the case of a new process, its anticipated effect.
- **Documentation.** A textual value that informally describes the work of the process; for example, the activities completed and the resources involved.
- **Process owner.** A textual value that defines the process owner, the person in the organisation who has the overall responsibility for this process and who manages the changes and plans for changes.
- **Process actors.** A textual value that defines the actors needed to run a process. Typically, their skill levels are described.
- **Priority.** A textual value that describes the priority of a process; for example, whether it's a core process, a support process, an administrative process and so on.

- **Risks.** A textual value that describes the risk of the process; for example, what can go wrong either when executing this process or when implementing this process in the business.
- **Possibilities.** A textual value that describes the potential of a process; for example, the opportunities for improving or using this process in the future.
- **Time.** A numerical value that approximates the execution time of the process.
- **Cost.** A numerical value that approximates the cost of executing the process.

B.4 Process object in UML process diagram:

- **Goal objects.** A goal object from a goal/problem diagram that has been allocated to a process. A goal object is drawn above the process diagram and attached with a dependency that is stereotyped to <<achieve>> from the process to the goal object (showing that the process attempts to achieve the goal).
- **Input objects.** Objects that are either consumed or refined in the process. The input objects are resources and as such can be stereotyped to <<physical>>, <<abstract>>, <<people>> or <<information>>. They are connected with dashed lines from the object to the process. Input objects are normally placed to the left of the process.
- **Output objects.** Objects that are produced by the process or that are the results of the refinement of one or more input objects. The output objects are also resources and are connected with a dashed line from the process to the output object. Output objects are placed to the right of the process.

- **Supplying objects.** Resources that are participating in the process but are not refined or consumed. These objects are drawn below the process with a dependency from the object to the process. The dependency is stereotyped to <<supply>>.
- **Controlling objects.** Resources that control or run the process. Such objects are normally drawn above the process, with a dashed line from the object to the process. The stereotype of the dependency is <<control>>.

B.5 Process diagram of the SLS rapid prototyping subprocess

The input objects of this subprocess are "Process plan", which is a physical object and "Prototype production order", which is information. There is one output object – "Prototype", which is also a physical object. The supplying resources are represented by "Materials and SLS machine", "Project engineer" and "Quality control manager" that are of <<physical>> and <<people>> resource types, respectively. The process is controlled by the "RP Project manager", which is a <<people>> type resource and the goal of the process is to produce an SLS Dura Form model, a quantitative goal.

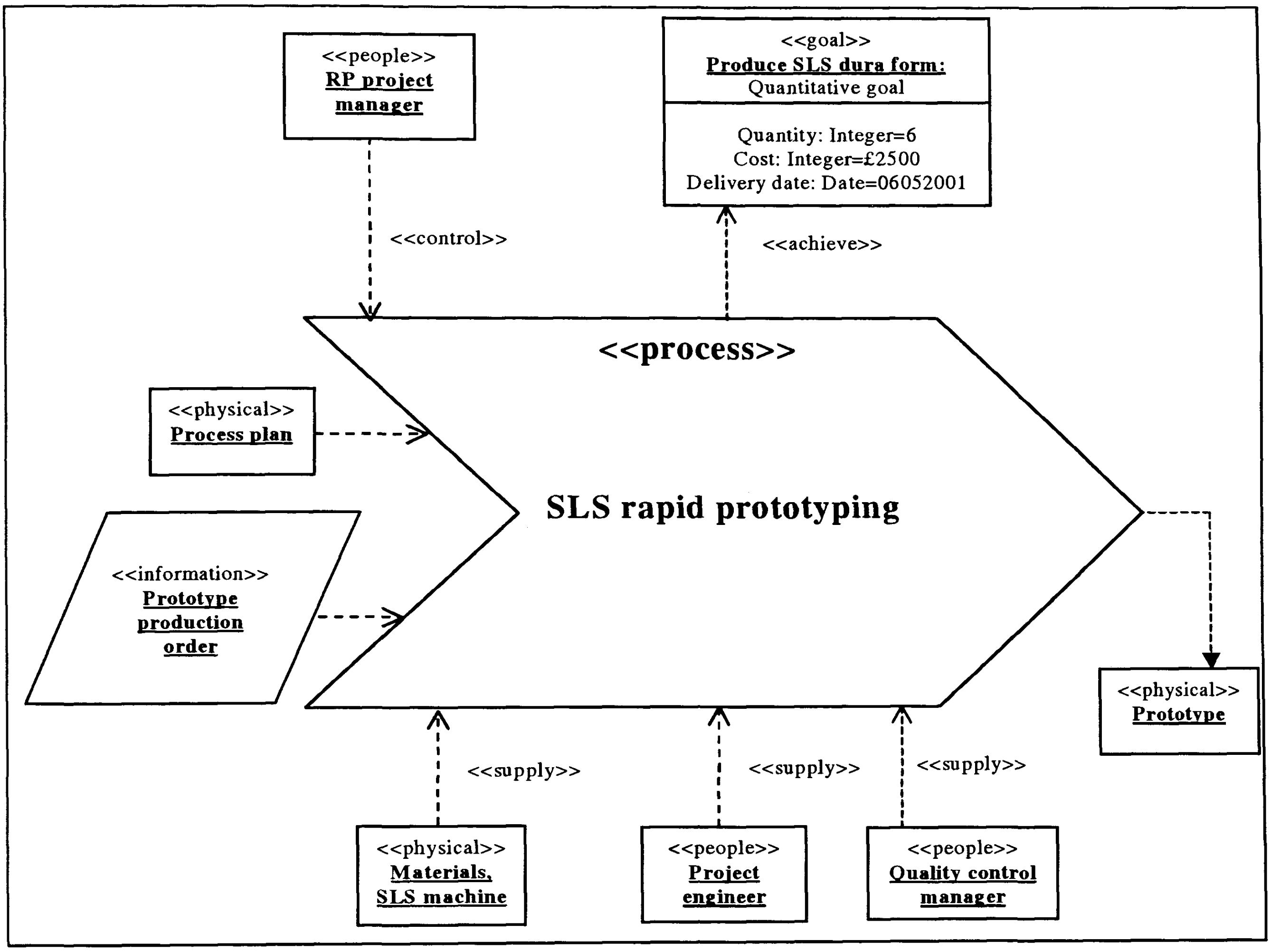


Fig. B.1 - Process diagram of the SLS rapid prototyping process

B.6 Process diagram of the Quality check subprocess

The process diagram of the Quality check subprocess is shown in [Fig. 3.9]. The input object of this subprocess is "Produced parts", which is a physical object. There are two output objects – "Parts calibrated", which is a physical object and "Quality check passed", which is information. The supplying resources are represented by "Production facilities", a physical resource and "SLS project manager" from the resource type <<people>>. The process is controlled by the "Quality control manager", which is a <<people>> type resource and the goal of the process is customer satisfaction, a qualitative goal. The Quality check process does not have any subprocesses but it contains a number of activities, which are presented in detail further on in this case study.

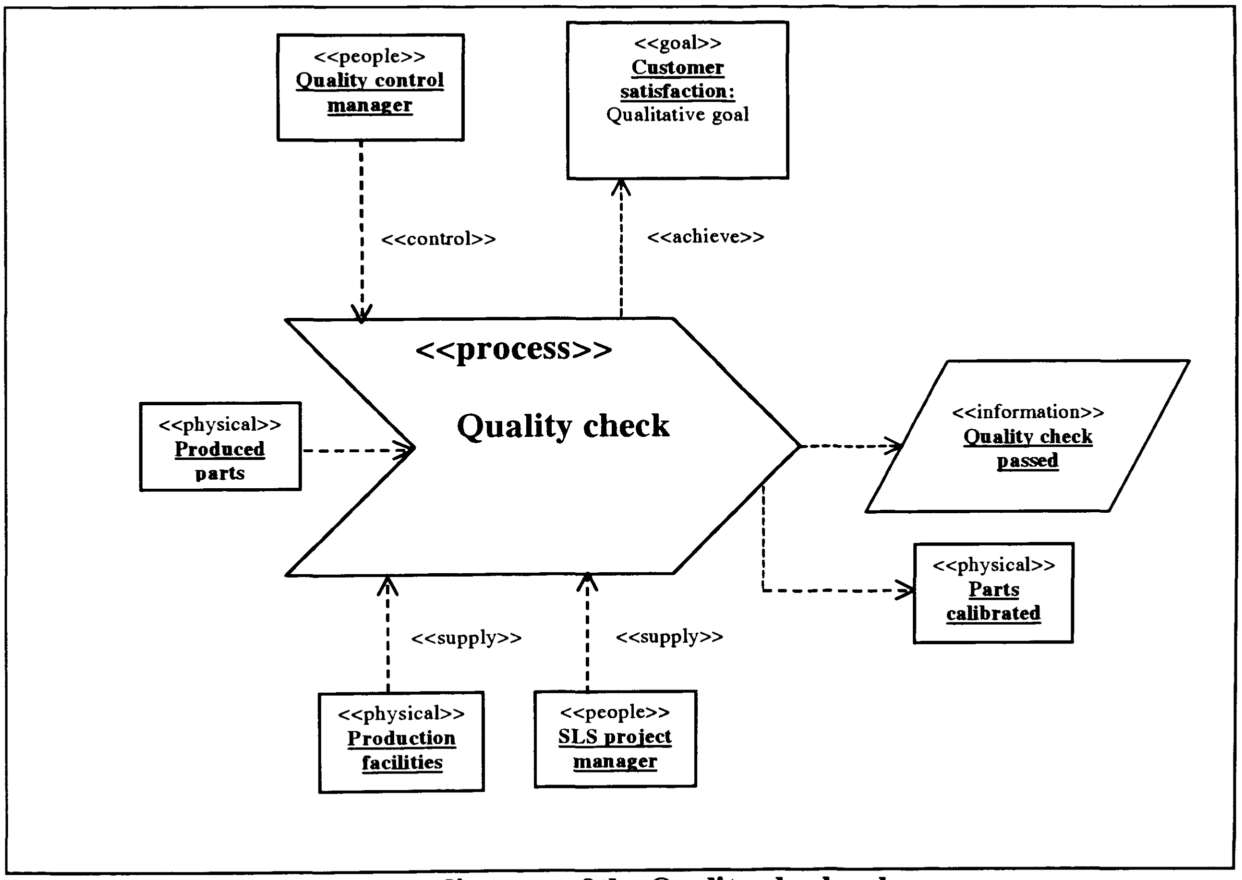


Fig. B.2 - Process diagram of the Quality check subprocess

B.7 Resource use pattern for the SLS rapid prototyping subprocess

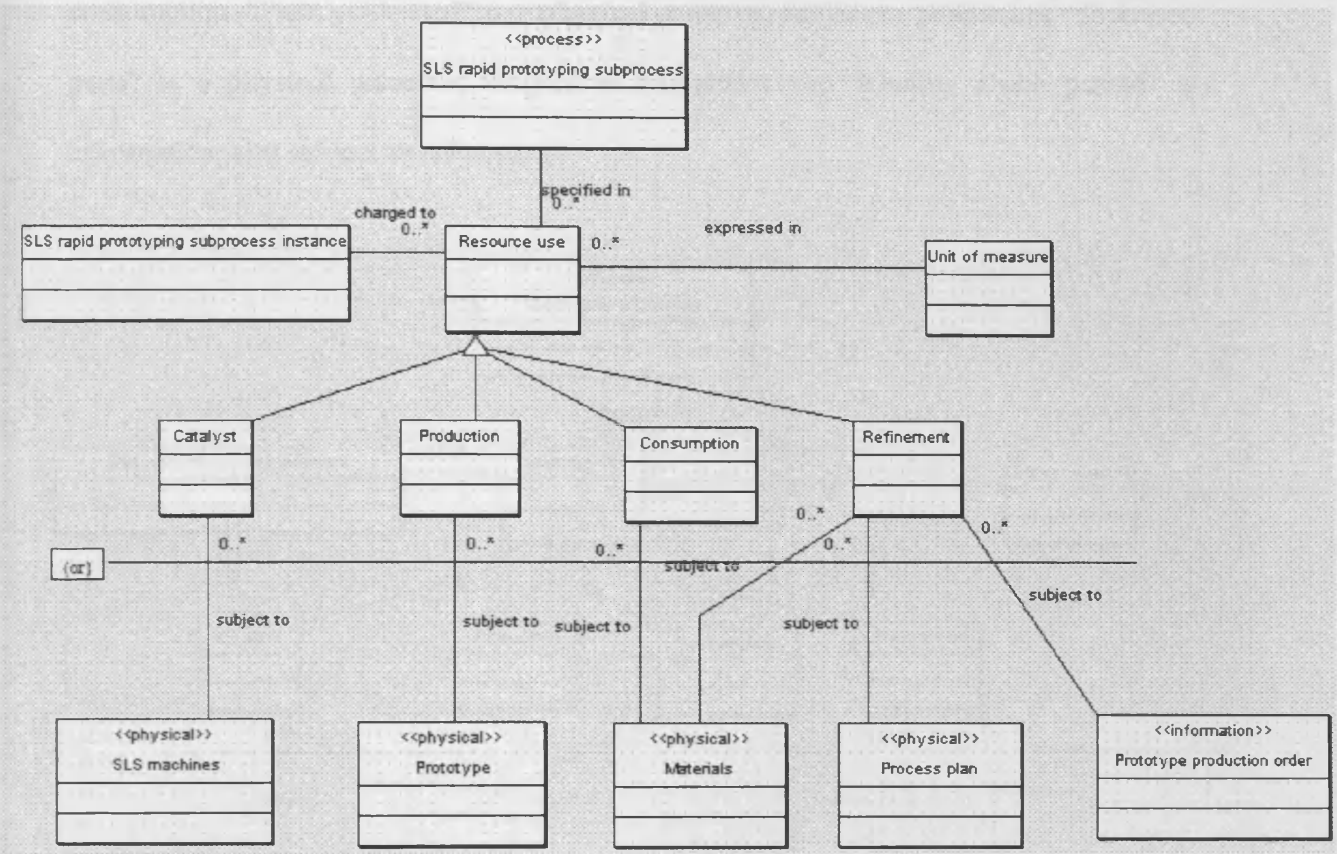


Fig. B.3 - Resource use pattern for the SLS rapid prototyping subprocess

Most of the resources of this process are similar to the ones used in the main business process, since Prototyping is a subprocess. SLS machines, Prototype and Materials are the same as in the main business process but Process plan is a new physical resource that is subject to refinement. Another new resource is the Prototype production order, which is information and subject to refinement.

B.8 Resource use pattern for the Quality check subprocess

The physical resource "Production facilities" is a resource linked both to catalyst and consumption. "Parts calibrated" is a physical resource, subject to production. "Produced parts" is a physical resource, subject to refinement and "Quality check passed" is information, also subject to refinement.

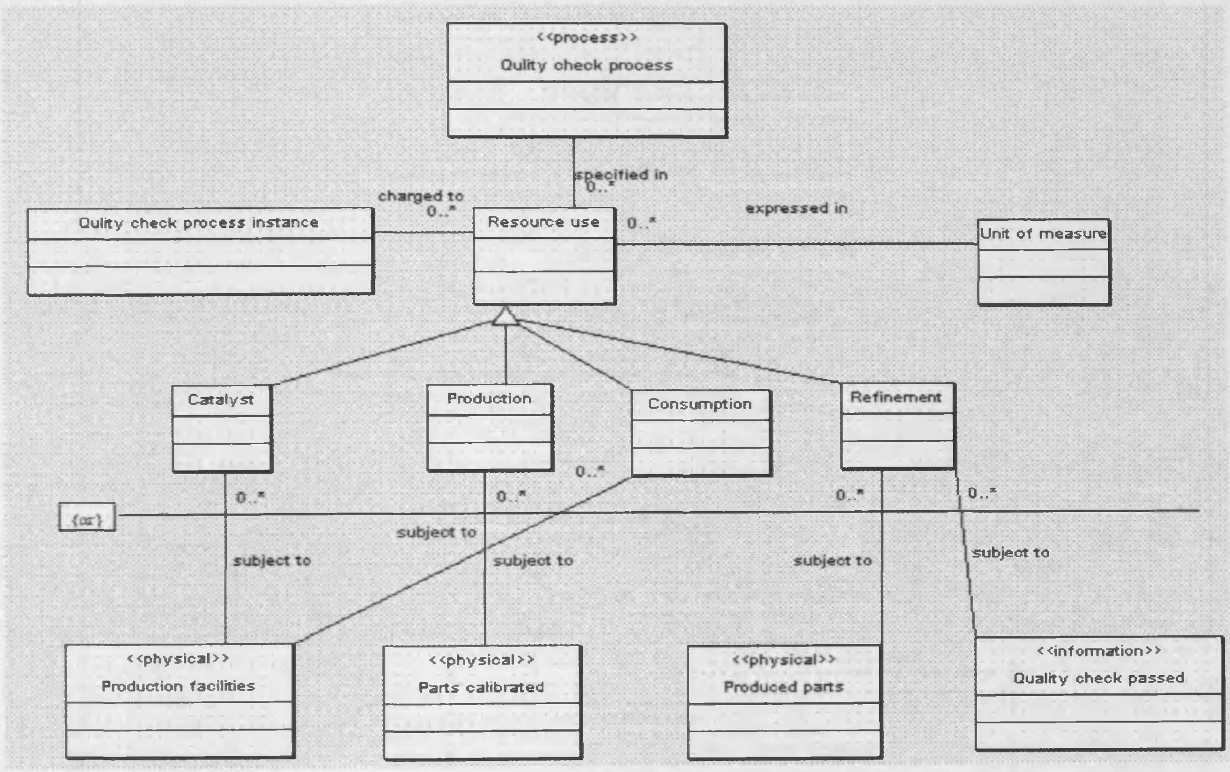


Fig. B.4 - Resource use pattern of the Quality check subprocess

B.9 Activity diagram for the SLS rapid prototyping subprocess

The process starts with the activity "Check the STL files' availability" and finishes with the event "Send delivery note to the customer".

B.10 Activity diagram for the Quality check subprocess

This process starts with the activity "Quality check" and finishes either with the events "Parts ready" or "Parts calibrated", which leads to the feedback of "setting-up process parameters".

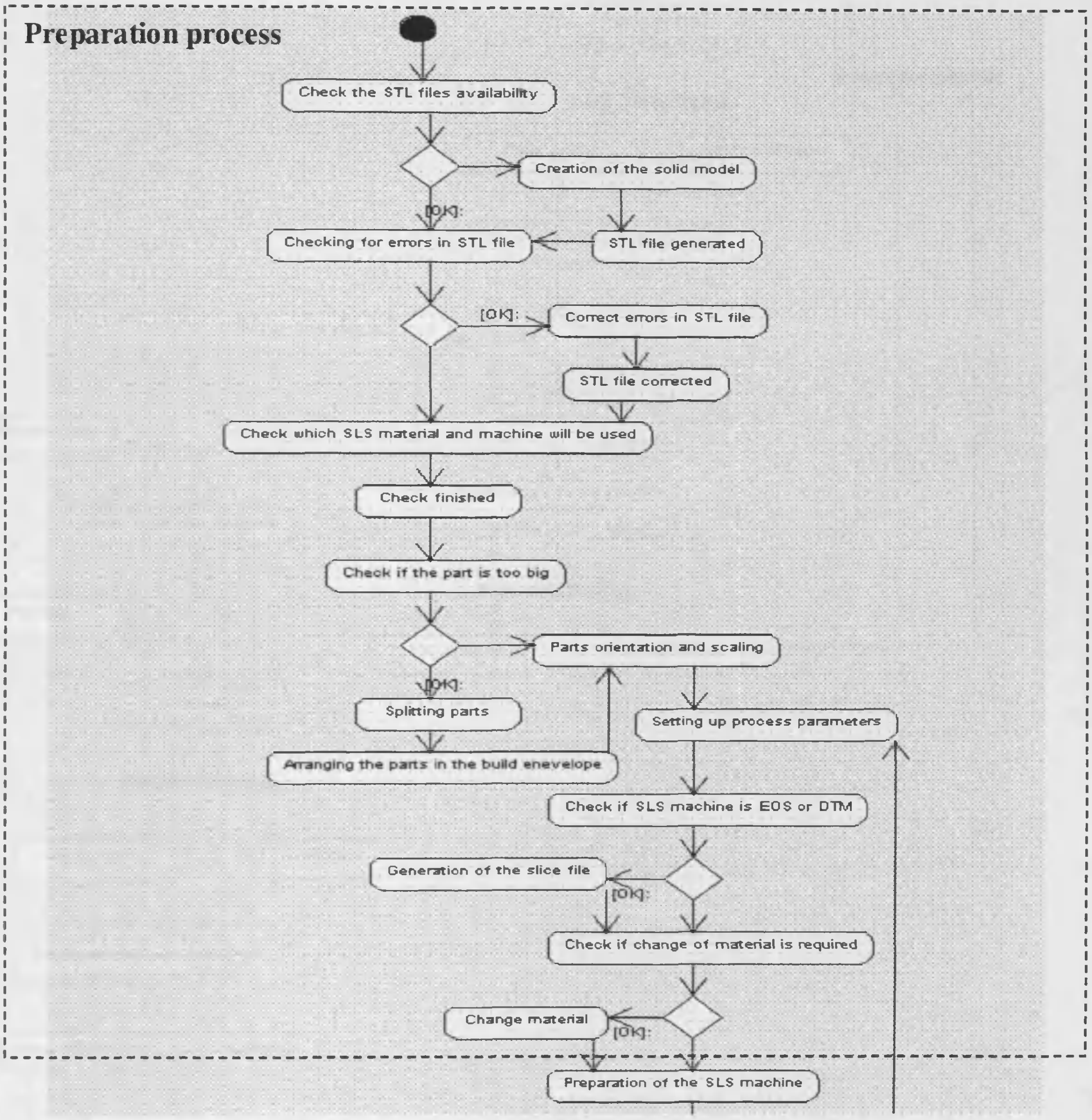
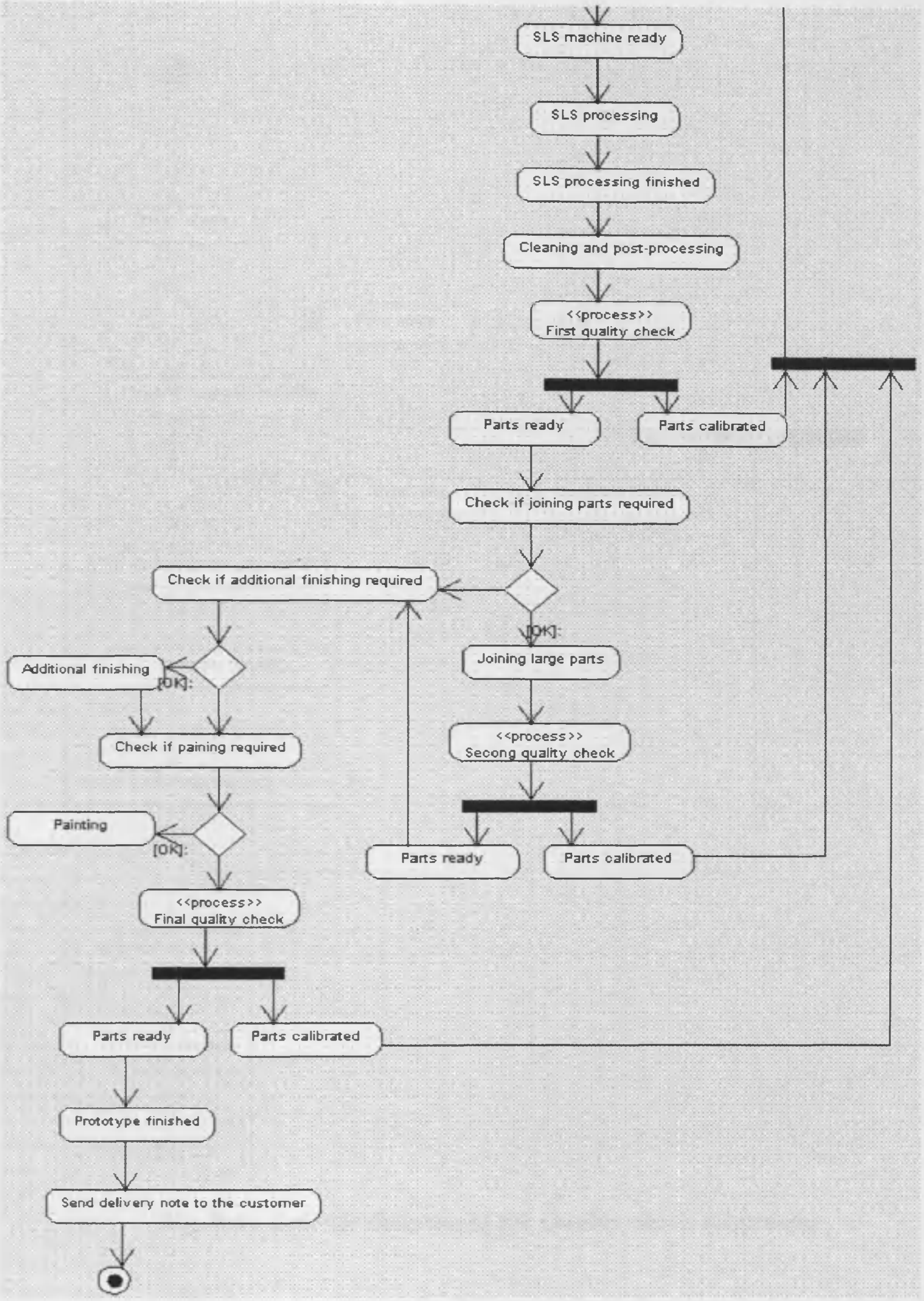


Fig. B.5 - Activity diagram of the SLS rapid prototyping subprocess (continues on the next page)



Activity diagram of the SLS rapid prototyping subprocess (continuation)

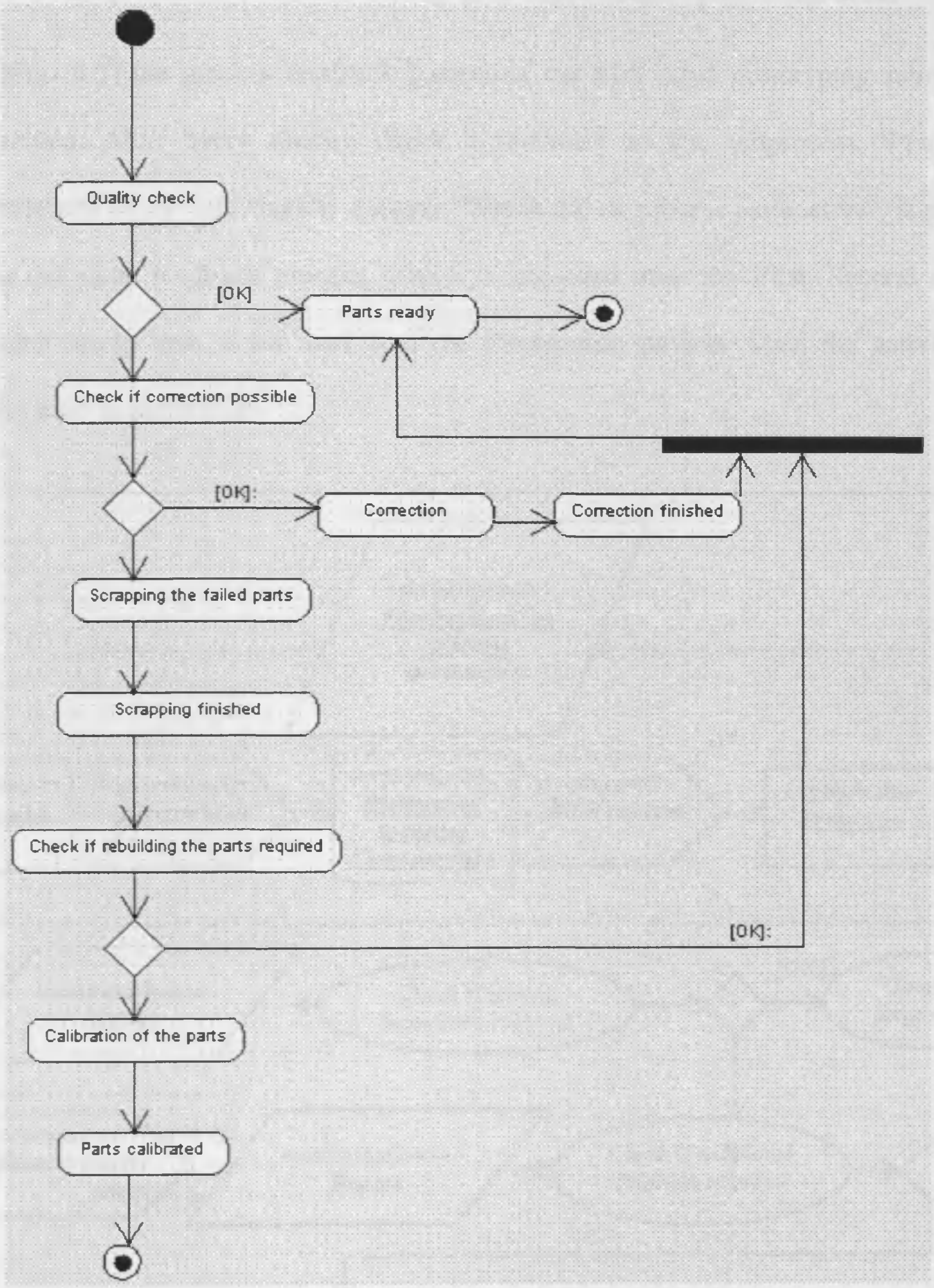


Fig. B.6 - Activity diagram of the Quality check subprocess

B.11 Process feedback pattern for the SLS rapid prototyping subprocess

In [Fig. B.7] the process feedback pattern of the SLS rapid prototyping subrpcoess is presented. After every quality check a feedback to the subprocess "Preparation", represented by the information resource "Feedback on process parameters", is generated. It is the same feedback process, which is triggered after the First, Second and Final quality checks and is fed back into the Preparation process when the activity "Parts calibrated" is performed.

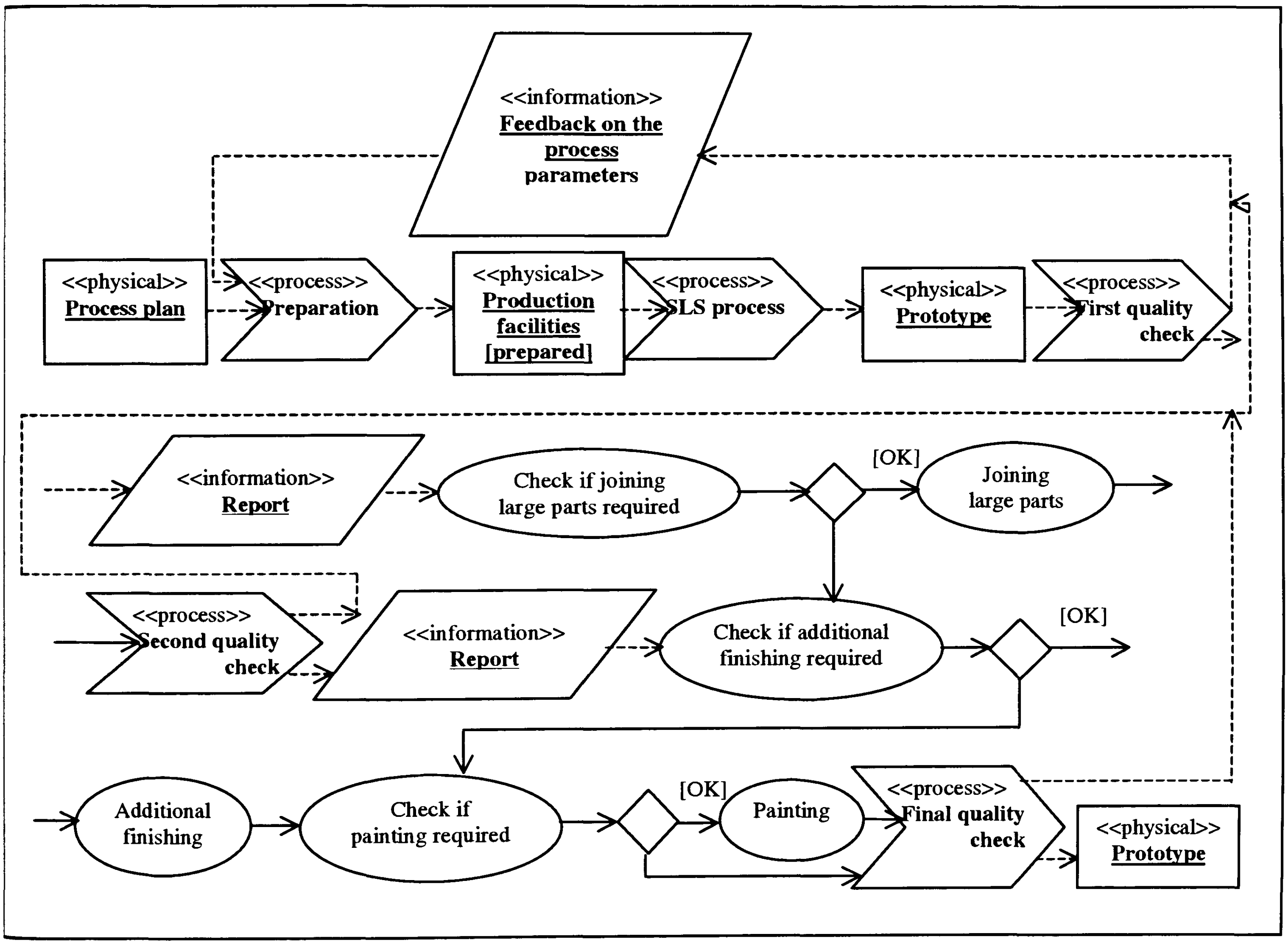


Fig. B.7 - Process feedback pattern of the SLS rapid prototyping subprocess

The SLS process is presented in [Fig. B.8]. It consists of three activities – "Preparation of the SLS machine", "SLS processing" and "Cleaning and post-processing". The First, Second and Final quality checks are represented by the same subprocess "Quality check", described in the activity diagram in [Fig. B.6]. The subprocess "Preparation" is not represented separately but it is a part of the activity diagram of the SLS rapid prototyping subprocess shown in [Fig. B.5]. The Preparation process starts with the activity "Checking the STL files' availability" and ends with the activity "Change material".

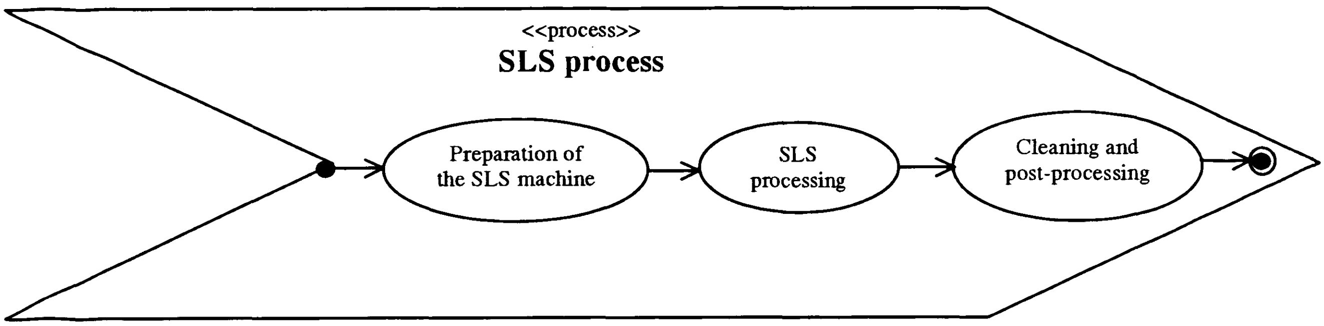


Fig. B.8 - The SLS subprocess of the Prototyping subprocess

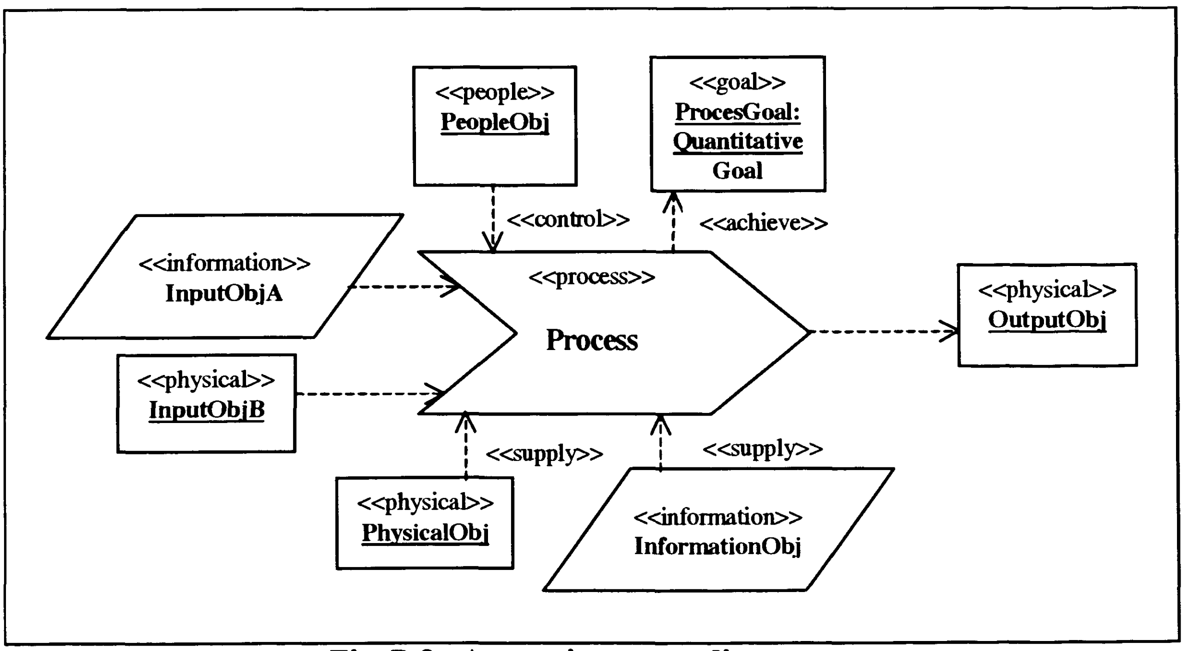


Fig. B.9 - A generic process diagram

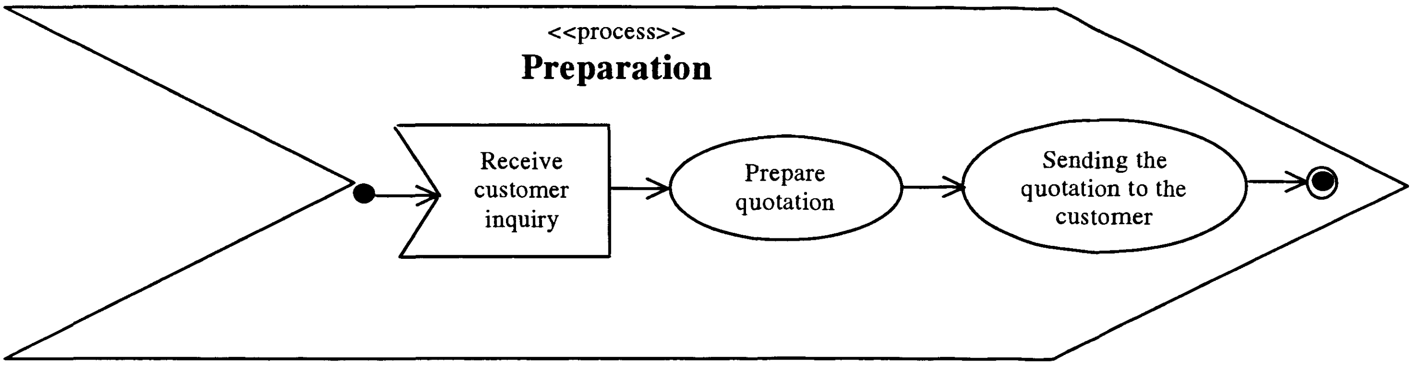


Fig. B.10 - The Preparation subprocess of the main business process

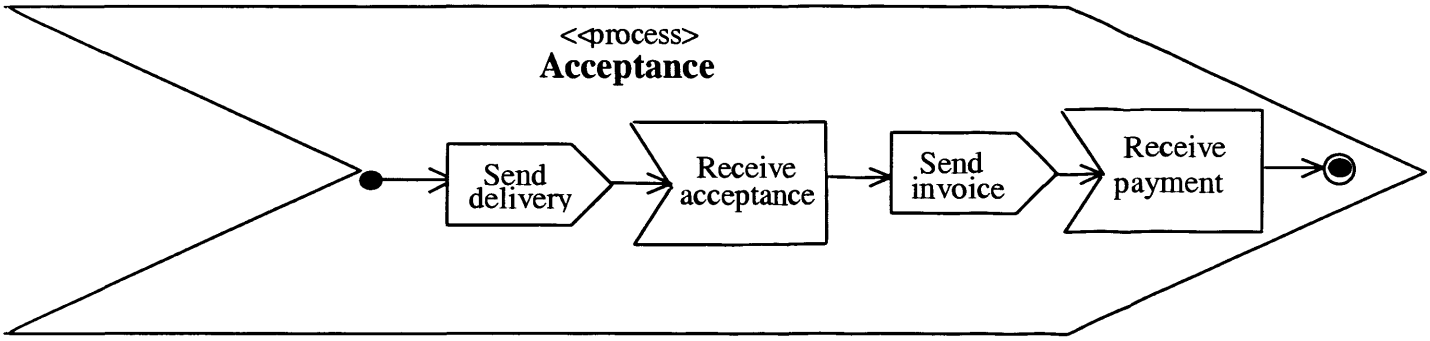


Fig. B.11 - The Acceptance subprocess of the main business process

The Preparation process consists of the event "Receive customer inquiry" and two activities: "Prepare quotation" and "Sending the quotation to the customer". Another simple and straightforward process is Acceptance, presented in the Appendix B in [Fig. B.11]. It consists of the following four events, representing the interaction between the customer and supplier: "Send delivery", "Receive acceptance", "Send invoice" and "Receive payment".

The Negotiation process is presented in the Appendix B in [Fig. B.14]. It involves a lot of checks and decisions, which imply again, strong interaction between the customer and the supplier. If there is no response from the customer, the order is stopped and the process finishes. If the order is placed and there are machines available, the CAD files are also available and there are no outstanding payments from the customer, then the process finishes and the next phase – Accomplishment may start. If during this process the activity "Quotation revised" is carried out, it leads to feedback to the Preparation process. The Negotiation process has three different outputs, one of which serves as a feedback to the Preparation process.

The Accomplishment process is shown in [Fig. B.15]. It starts with the activity "Start RP project" and invokes the subprocess "Prototyping". After the prototype is produced, a quality control is performed, which leads to two different activities – if the quality check passes, then a project report is produced and the process terminates; if the check fails, the process plan is revised and the customer is informed. At this stage another feedback is generated, represented by the information resource "Feedback on process plan". This feedback is input for the subprocess "Prototyping" when the revised process plan is accepted by the customer. If the customer is not satisfied, there is no order, the process is completed and the overall process is terminated. The satisfactory end of the process is marked by the activity "Project report". It indicates that the prototype physical resource is ready and this is an input for the process "Acceptance".

B.12 Resource use pattern for the main business process

The process diagram contains the main business process that uses as resources the SLS machines and materials. The process takes CAD files and customer inquiry as input and delivers a prototype. The class diagram demonstrates how the process uses resources. The model indicates that the resource use is specified in the main business process and charged to the instance of this process. Each resource use is expressed in a unit of measure. The Resource use defines the use of the resources or the resource types. A resource is typically produced, consumed, refined or acts as a catalyst. However, a Resource use object refers to only one resource object or one resource type object, which is designated by the {or} constraint over the Resource use types. The use of the SLS machines – a physical resource, is the catalyst, meaning that the machines are used, not consumed, produced or refined. The Prototype - physical resource, is produced during the process, the Materials - physical resource, are consumed and refined to produce the prototype. The CAD file is a physical resource, and Customer inquiry is an abstract resource and they are both subject to refinement.

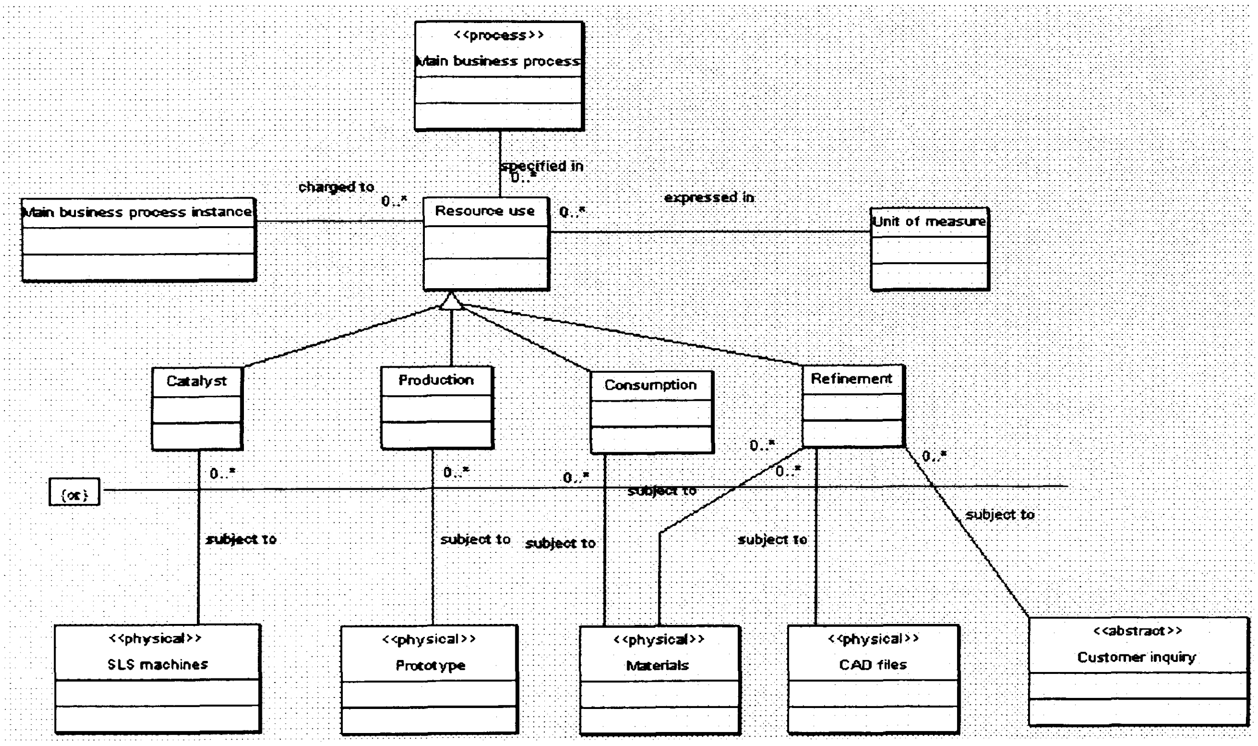


Fig. B.12 - Resource use pattern for the main business process

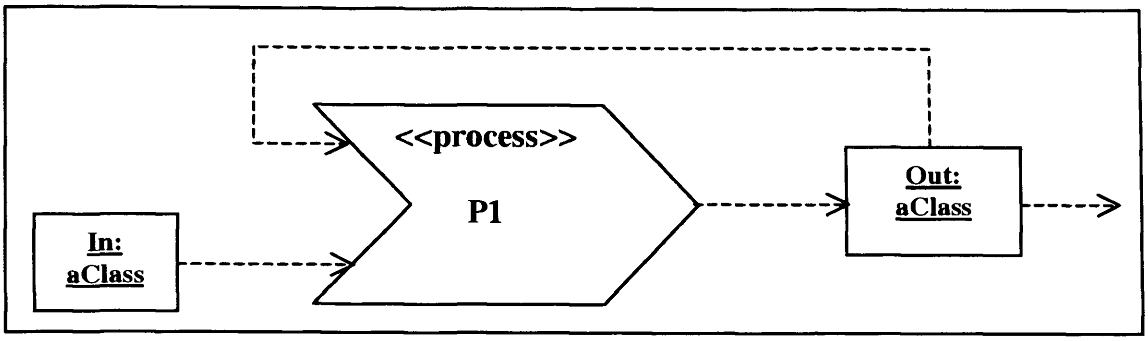


Fig. B.13 - The structure of the Process feedback pattern

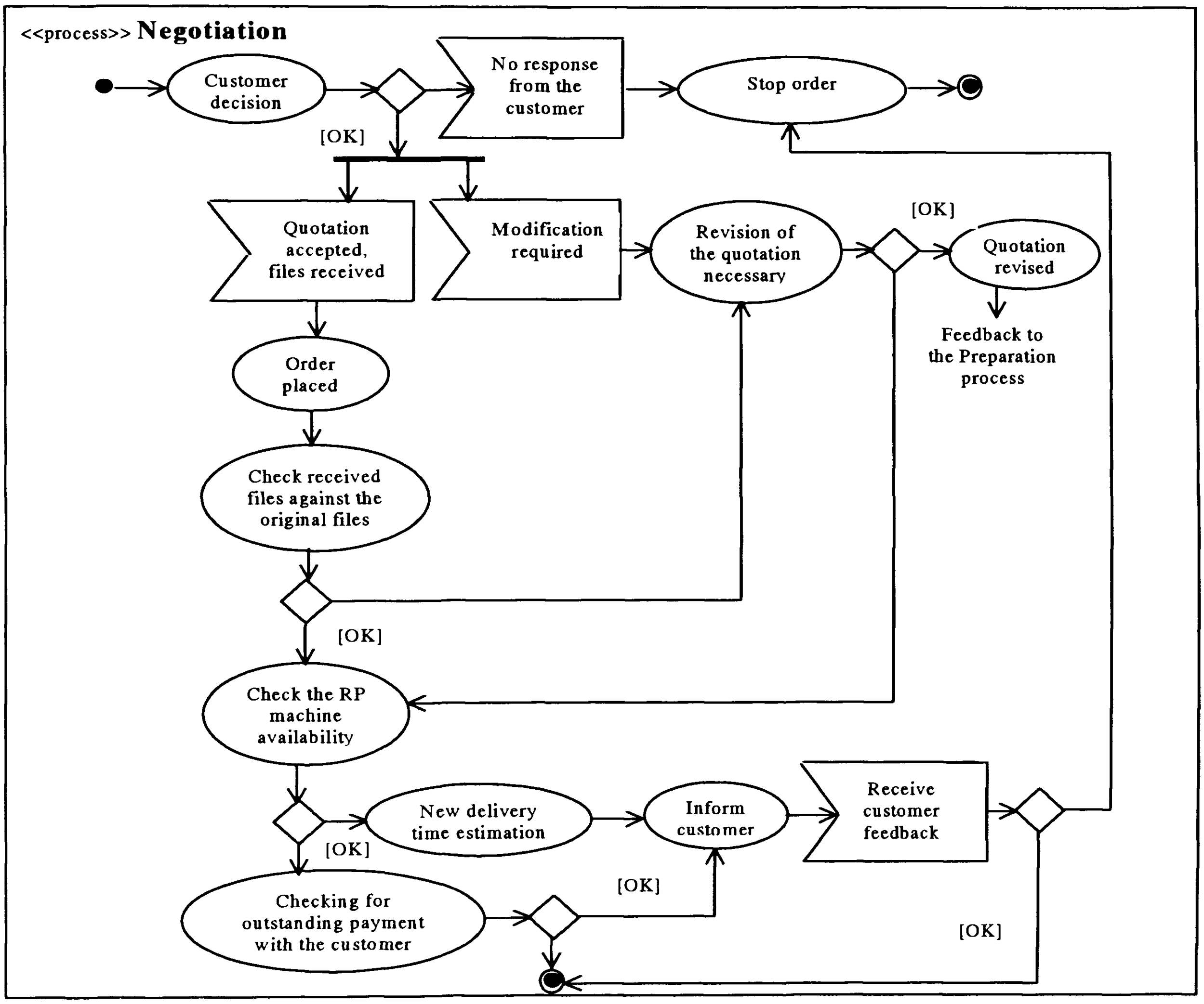


Fig. B.14 - The Negotiation subprocess of the main business process

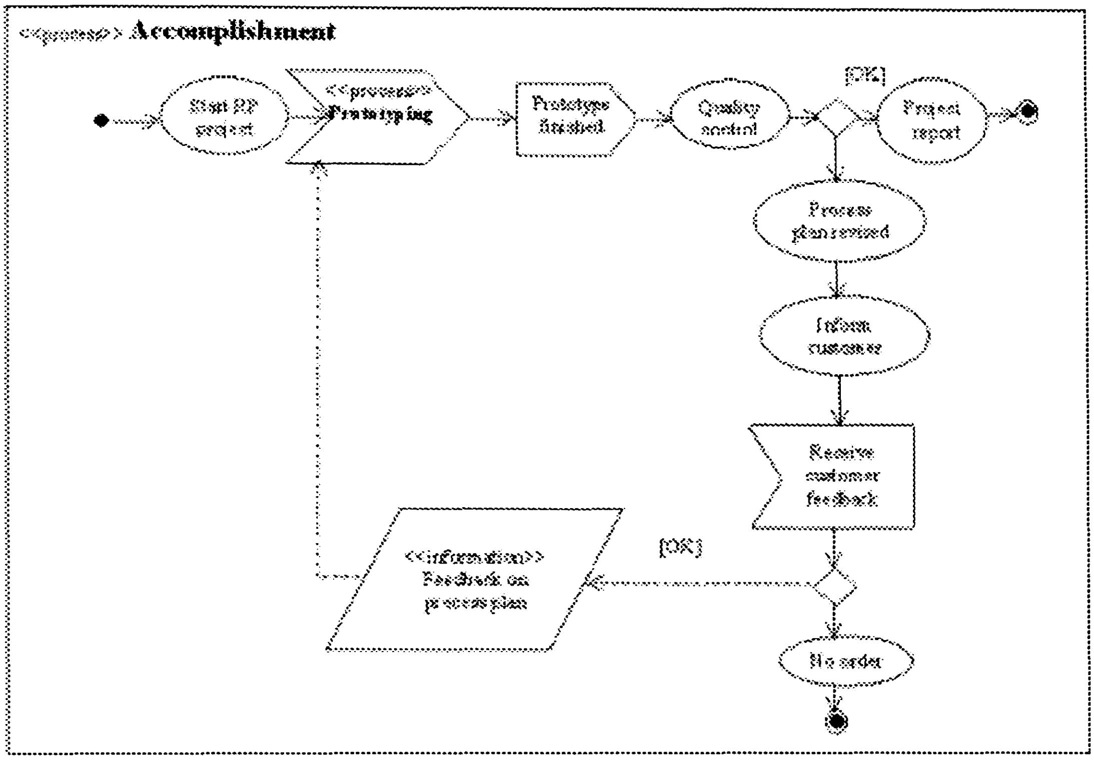


Fig. B.15 - The Accomplishment subprocess of the main business process

Appendix C - Supporting tables for the extended P/p graph and modelling the subprocesses of the main business process

Product	Description	Collection or distribution gate	Class of product	Graphical symbol
P_1	STL files availability checked	d(P_2,P_3)	hard	⟶
P_2	STL files not available		hard	⟶
P_3	STL files available		hard	⟶
P_4	STL files generated		hard	⟶
P_5	STL files ready	c(P_3,P_4)	hard	⟶
P_6	Errors checked	d(P_7,P_8)	hard	⟶
P_7	Errors found		hard	⟶
P_8	Errors not found		hard	⟶
P_9	STL files corrected		hard	⟶
P_{10}	Final STL file	c(P_8,P_9)	hard	⟶
P_{11}	Check finished		hard	⟶
P_{12}	Parts checked	d(P_{13},P_{14})	hard	⟶
P_{13}	No		hard	⟶
P_{14}	Yes		hard	⟶
P_{15}	Parts split		hard	⟶
P_{16}	Parts orientation and scaling selected		hard	⟶
P_{17}	Parts arranged for building		hard	⟶
P_{18}	Arranging parts approved		hard	⟶
P_{19}	Parts prepared		hard	⟶
P_{20}	Parts to be oriented		hard	⟶
P_{21}	Parts to be build	c(P_{16},P_{22})	hard	⟶
P_{22}	Parts calibrated		hard	⟶
P_{23}	Process parameters set		hard	⟶
P_{24}	Machine checked	d(P_{25},P_{26})	hard	⟶
P_{25}	EOS machine		hard	⟶
P_{26}	DTM machine		hard	⟶
P_{27}	Slice file generated		hard	⟶
P_{28}	Check required	c(P_{26},P_{27})	hard	⟶

P_{29}	Check finished	$d(P_{30},P_{31})$	hard	→
P_{30}	Change of material required		hard	→
P_{31}	Change of material not required		hard	→
P_{32}	Material changed		hard	→
P_{33}	Material ready	$c(P_{31},P_{32})$	hard	→
P_{34}	SLS machine ready		hard	→
P_{35}	SLS processing finished		hard	→
P_{36}	Cleaning and post-processing finished		hard	→
P_{49}	Check finished	$d(P_{50},P_{51})$	hard	→
P_{50}	Joining parts required		hard	→
P_{51}	Joining parts not required		hard	→
P_{52}	Joining parts finished		hard	→
P_{53}	Second quality check finished		hard	→
P_{54}	Check finished	$d(P_{55},P_{56})$	hard	→
P_{55}	Additional finishing required		hard	→
P_{56}	Additional finishing not required		hard	→
P_{57}	Additional finishing ready		hard	→
P_{58}	Parts finishing ready		hard	→
P_{59}	Check if painting required	$d(P_{60},P_{61})$	hard	→
P_{60}	Painting required		hard	→
P_{61}	Painting not required		hard	→
P_{62}	Painting finished		hard	→
P_{63}	Parts ready for final quality check	$c(P_{61},P_{62})$	hard	→ →
P_{64}	Prototype finished		hard	→
P_{65}	Parts parameters ready		hard	→
P_{66}	Parts parameters after actuation		hard	→
P_{67}	Parts joint		hard	→

Table C.1 - Products for the subprocess Prototyping

Process	Description	Owner	Input product	Output product	Document	Class of process	Graphical symbol
p_1	Check for STL files availability	RP project manager	P_{14}	P_1	Prototype production order	hard	
p_2	Solid model created	Project engineer	P_2	P_4	Drawings, IGES, other 3D CAD formats	hard	
p_3	Checking for errors in STL file	Project engineer	P_5	P_6	STL files	hard	
p_4	Correct errors in STL file	Project engineer	P_7	P_9	STL files	hard	
p_5	Checking which SLS material and machine will be used	Project engineer	P_{10}	P_{11}	STL files	hard	
p_6	Checking if the part is too big	Project engineer	P_{11}	P_{12}	Report	hard	
p_7	Part orientation and scaling	Project engineer	P_{13}	P_{16}	STL files	hard	
p_8	Splitting parts	Project engineer	P_{14}	P_{15}	-	hard	
p_9	Arranging the parts in the build envelope	Project engineer	P_{15}	P_{17}	-	hard	
p_{10}	Setting up process parameters	Project engineer	P_{21}	P_{23}	STL files	hard	
p_{11}	Checking if SLS machine is EOS or DTM	Project engineer	P_{23}	P_{24}	STL files	hard	
p_{12}	Generation of the slice file	Project engineer	P_{25}	P_{27}	-	hard	
p_{13}	Check if change of	Project engineer	P_{28}	P_{29}	-	hard	

	material is required						
p_{14}	Change material	Project manager	P_{30}	P_{32}	-	hard	☐
p_{15}	Preparation of the SLS machine	SLS project manager	P_{33}	P_{34}	Slice file	hard	☐
p_{16}	SLS processing	SLS project manager	P_{34}	P_{35}	-	hard	☐
p_{17}	Cleaning and post-processing	SLS project manager	P_{35}	P_{36}	-	hard	☐
p_{18} (sub-process)	First quality check	Quality control manager	P_{36}	P_{48}	-	hard	☐
p_{24}	Check if joining parts is required	SLS project manager	P_{48}	P_{49}	-	hard	☐
p_{25}	Joining large parts	SLS project manager	P_{50}	P_{52}	-	hard	☐
p_{26} (sub-process)	Second quality check	Quality control manager	P_{67}	P_{53}	-	hard	☐
p_{27}	Check if additional finishing required	SLS project manager	P_{53}	P_{54}	-	hard	☐
p_{28}	Additional finishing	SLS project manager	P_{55}	P_{57}	-	hard	☐
p_{29}	Check if painting is required	SLS project manager	P_{58}	P_{59}	-	hard	☐
p_{30}	Painting	RP manager	P_{60}	P_{62}	-	hard	☐
p_{31} (sub-process)	Final quality check	Quality control manager	P_{63}	P_{64}	-	hard	☐

Table C.2 - Processes for the subprocess Prototyping

Feed back	Description	Input	Output	Comparator	Actuator	Sensor	Goal
F_1	Feedback for splitting the parts	P_{13}	P_{17}	Project engineer	Parts size	SLS project manager	Big parts to be split for production
F_2	Feedback for quality check	P_{16}	P_{22}	Quality manager	Process parameters	SLS project manager	To set up process parameters

Table C.3 - Feedbacks for the subprocess Prototyping

Product	Description	Collection or distribution gate	Class of product	Graphical symbol
P_{22}	Parts calibrated		hard	→
P_{37}	Quality check ready	d(P_{38},P_{39})	hard	→
P_{38}	Not passed		hard	→
P_{39}	Passed		hard	→
P_{40}	Check finished	d(P_{41},P_{42})	hard	→
P_{41}	Yes		hard	→ →
P_{42}	No		hard	
P_{43}	Correction finished		hard	⇒ →
P_{44}	Scrapping finished		hard	⇛
P_{45}	Rebuilding check	d(P_{46},P_{47})	hard	
P_{46}	Yes		hard	
P_{47}	No		hard	
P_{48}	Parts ready	c(P_{39}, P_{43}, P_{47})	hard	→

Table C.4 - Products for the subprocess Quality check

Process	Description	Owner	Input product	Output product	Document	Class of process	Graphical symbol
p_{18}	Quality check	Quality control manager	P_{36}	P_{37}	-	hard	
p_{19}	Check if correction possible	SLS project manager	P_{38}	P_{40}	-	hard	
p_{20}	Correction	SLS project manager	P_{41}	P_{43}	-	hard	
p_{21}	Scrapping the failed parts	SLS project manager	P_{42}	P_{44}	-	hard	
p_{22}	Rebuilding the parts required	SLS project manager	P_{44}	P_{45}	-	hard	
p_{23}	Calibration of the parts	SLS project manager	P_{46}	P_{22}	-	hard	

Table C.5 - Processes for the subprocess Quality check

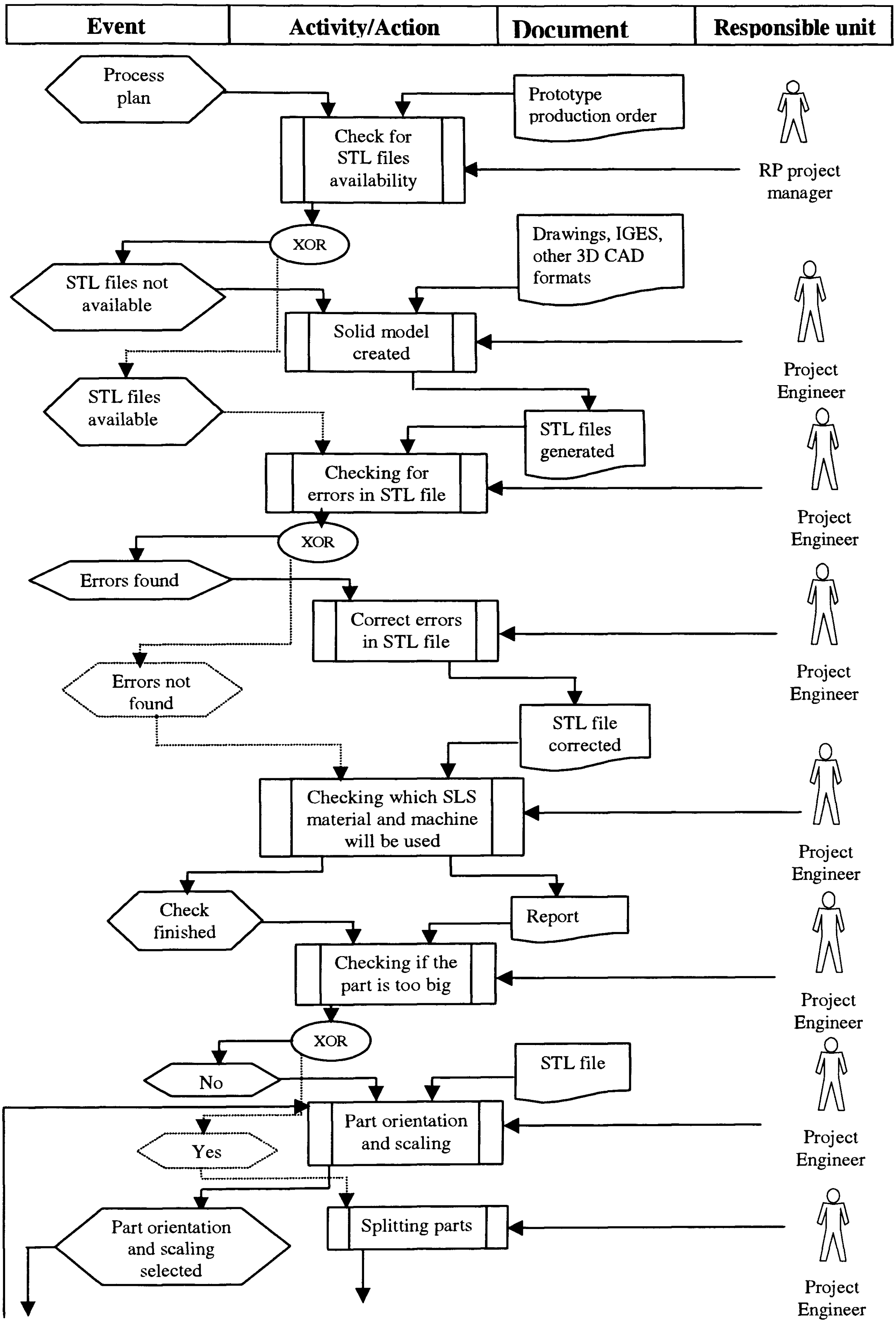
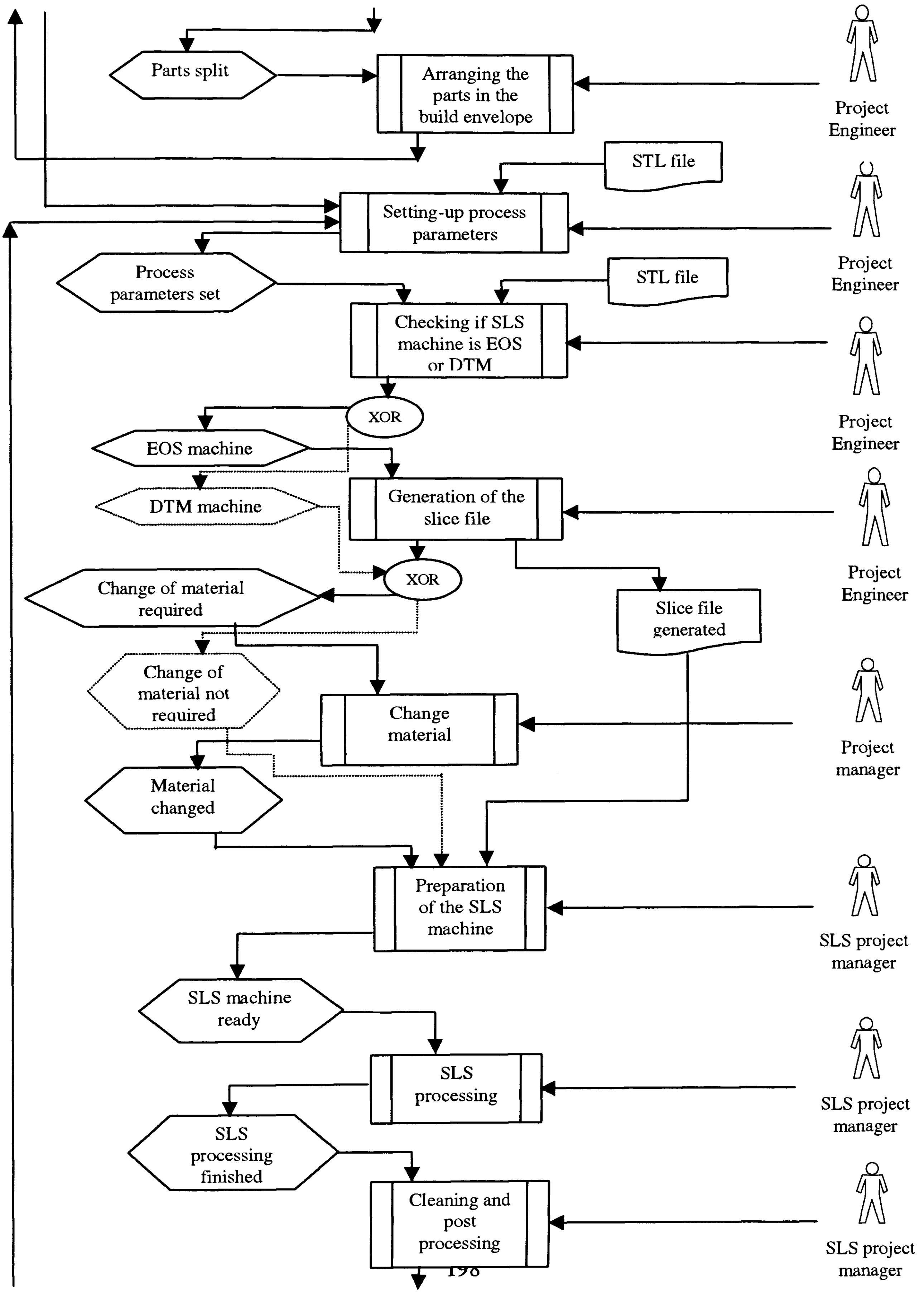
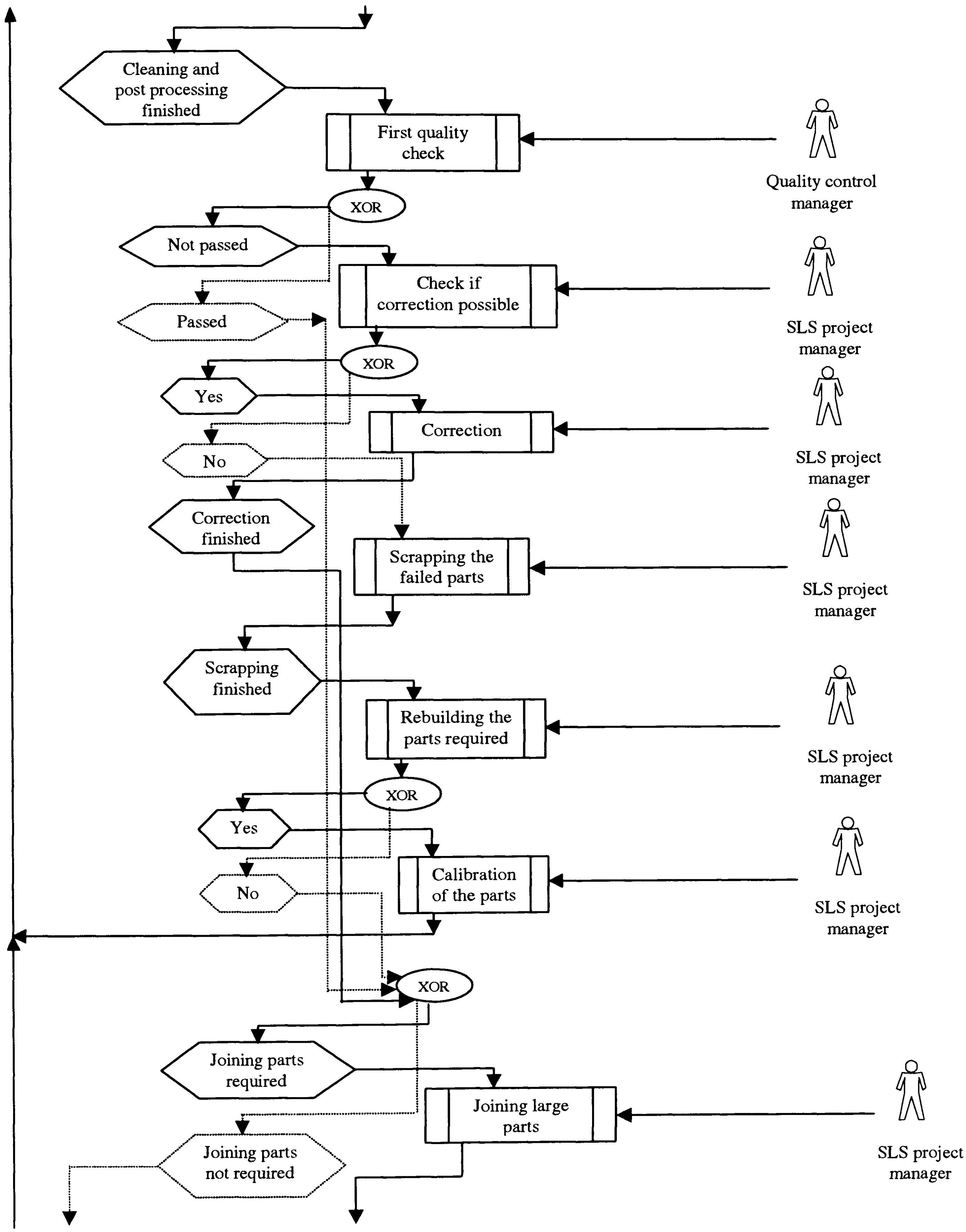
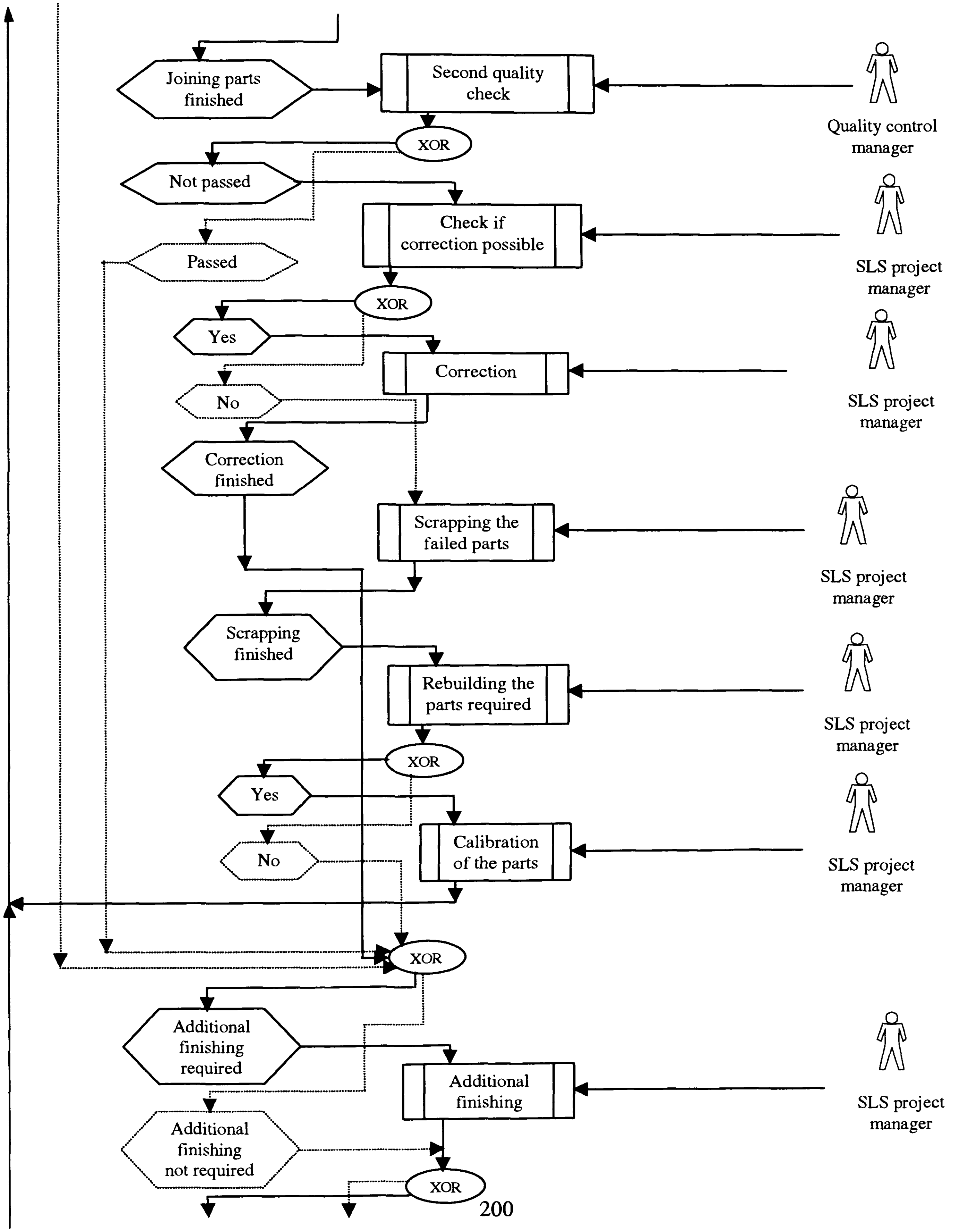
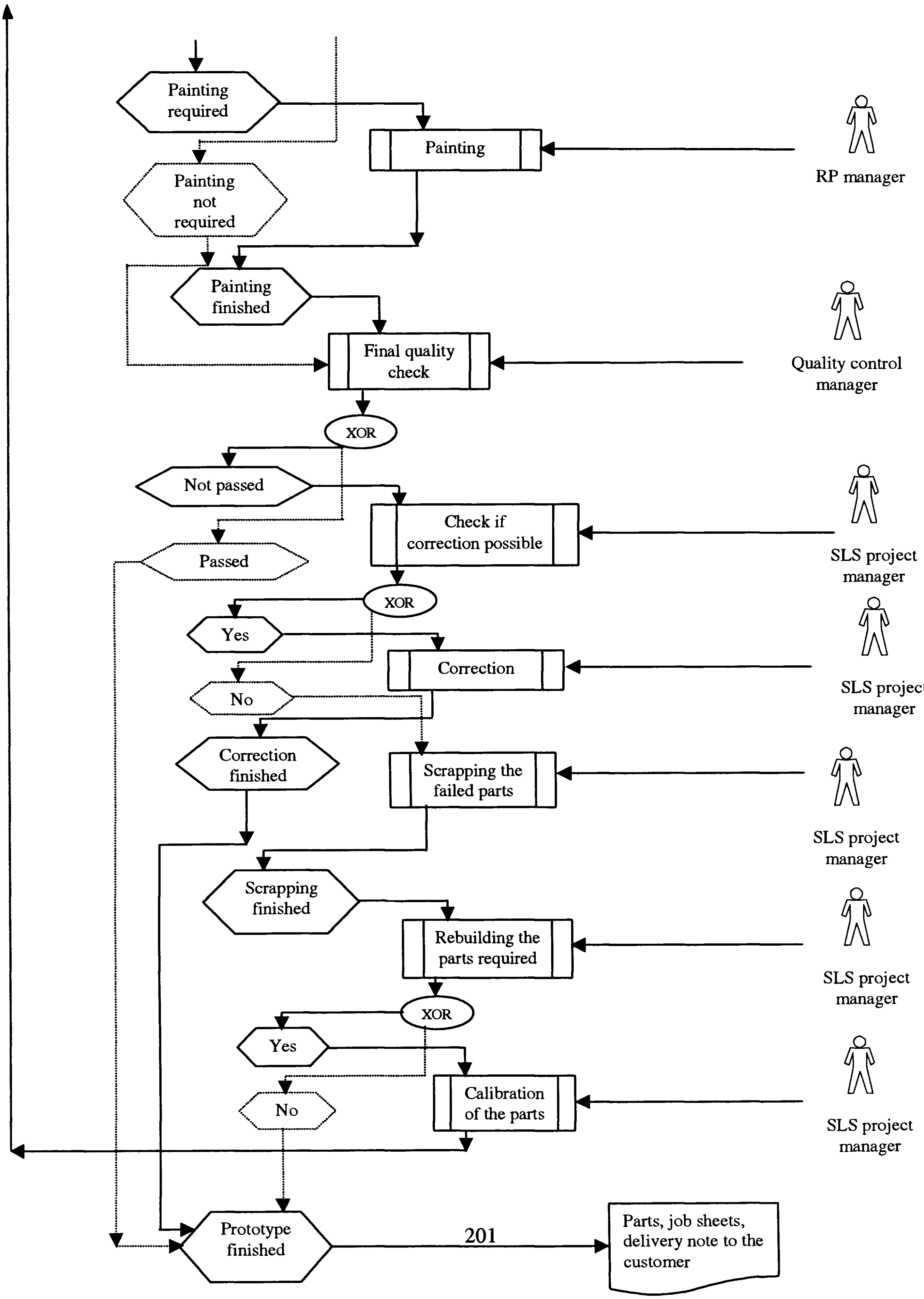


Fig. C.1 - The Prototyping subprocess (continues on the next five pages)


Parts split
Arranging the parts in the build envelope
Project Engineer
STL file
Setting-up process parameters
Project Engineer
Process parameters set
STL file
Checking if SLS machine is EOS or DTM
Project Engineer
XOR
EOS machine
DTM machine
Generation of the slice file
Project Engineer
XOR
Change of material required
Slice file generated
Change of material not required
Change material
Project manager
Material changed
Preparation of the SLS machine
SLS project manager
SLS machine ready
SLS processing
SLS project manager
SLS processing finished
Cleaning and post processing
SLS project manager


Cleaning and post processing finished
First quality check
Quality control manager
XOR
Not passed
Check if correction possible
SLS project manager
Passed
XOR
Yes
Correction
SLS project manager
No
Correction finished
Scrapping the failed parts
SLS project manager
Scrapping finished
Rebuilding the parts required
SLS project manager
XOR
Yes
Calibration of the parts
SLS project manager
No
XOR
Joining parts required
Joining large parts
SLS project manager
Joining parts not required


Joining parts finished
Second quality check
Quality control manager
XOR
Not passed
Passed
Check if correction possible
SLS project manager
XOR
Yes
No
Correction
SLS project manager
Correction finished
Scrapping the failed parts
SLS project manager
Scrapping finished
Rebuilding the parts required
SLS project manager
XOR
Yes
No
Calibration of the parts
SLS project manager
XOR
Additional finishing required
Additional finishing
SLS project manager
Additional finishing not required
XOR



Painting required
Painting
RP manager
Painting not required
Painting finished
Final quality check
Quality control manager
XOR
Not passed
Check if correction possible
SLS project manager
Passed
XOR
Yes
Correction
SLS project manager
No
Correction finished
Scrapping the failed parts
SLS project manager
Scrapping finished
Rebuilding the parts required
SLS project manager
XOR
Yes
Calibration of the parts
No
SLS project manager
Prototype finished
Parts, job sheets, delivery note to the customer

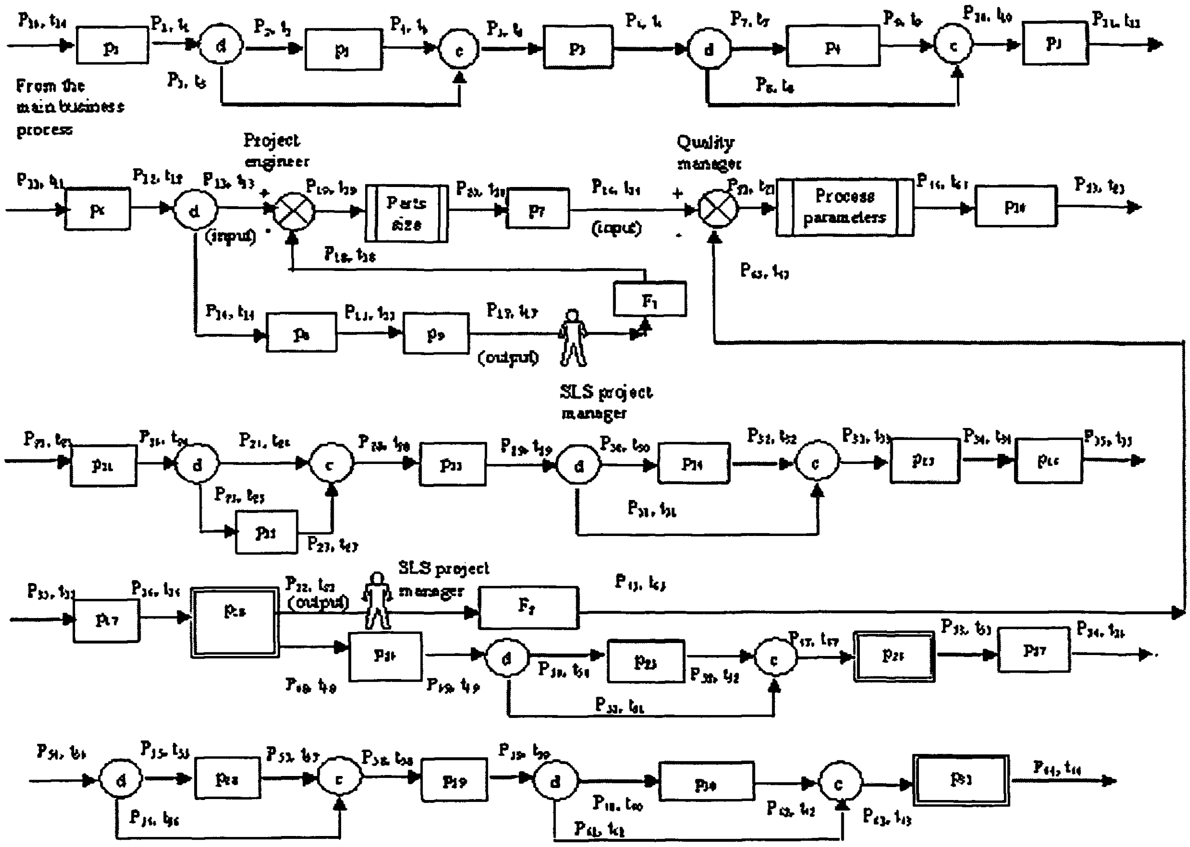


Fig. C.2 - Extended P/p graph of the "SLS rapid prototyping" subprocess

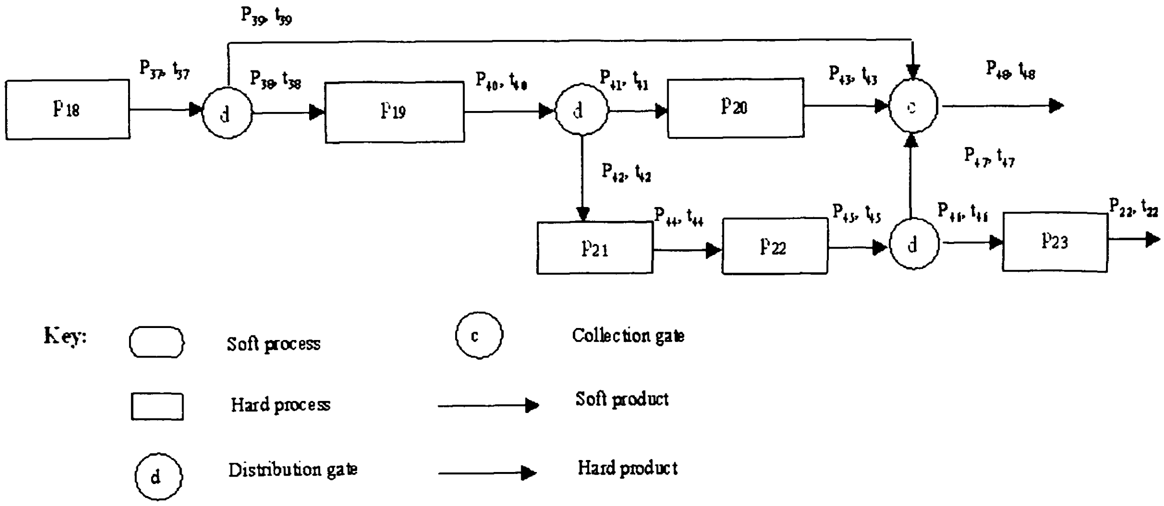


Fig. C.3 - Extended P/p graph of the subprocess "Quality check"

Appendix D - Supporting tables for the extended P/p graph of the benchmarking methodology

Product	Description	Class of product	Graphical symbol
P_1	Business process model	hard	$\longrightarrow$
P_2	List of customers	hard	$\longrightarrow$
P_3	List of information requirements	hard	$\longrightarrow$
P_4	Developed model to measure the business process quality	hard	$\longrightarrow$
P_5	Data collection sheet	hard	$\longrightarrow$
P_6	Responsibilities identified, people recruited	hard	$\longrightarrow$
P_7	Training completed	hard	$\longrightarrow$
P_8	List of benchmarking partners	hard	$\longrightarrow$
P_9	Data collection system implemented	hard	$\longrightarrow$
P_{10}	Partners approval	hard	$\longrightarrow$
P_{11}	Information organised and analysed	hard	$\longrightarrow$
P_{12}	Recommendations for action provided	hard	$\longrightarrow$
P_{13}	Report ready	hard	$\longrightarrow$
P_{14}	Recommendations for improvement provided	hard	$\longrightarrow$
P_{15}	Results implemented	hard	$\longrightarrow$
P_{16}	Improved process model	hard	$\longrightarrow$
P_{17}	Improved process model for benchmarking	hard	$\longrightarrow$
P_{18}	Process model after actuation	hard	$\longrightarrow$

Table D.1– Table of products for the benchmarking process

Feedback	Description	Input	Output	Comparator	Actuator	Sensor	Goal
F	Feedback for the process model	P_1	P_{16}	Benchmarking team	Cost, quality, time	Project manager	To optimise the business process model

Table D.2 - Table of feedbacks for the benchmarking process

Process	Description	Input product	Output product	Document	Class of process	Graphical symbol
p_1	Plan	P_{17}	P_5	-	hard	
p_2	Identify customers	P_{17}	P_2	List of customers	hard	
p_3	Identify the information requirements	P_2	P_3	List of inf. requirements	hard	
p_4	Define the specific subjects to be benchmarked	P_3	P_4	-	hard	
p_5	Identify the resources required	P_4	P_5	Data collection sheet	hard	
p_6	Collect	P_5	P_8	List of bench. partners	hard	
p_7	Form the benchmarking team	P_5	P_7	-	hard	
p_8	Define specific roles and team members' responsibilities	P_5	P_6	-	hard	
p_9	Train the team members in project management tools	P_6	P_7	-	hard	
p_{10}	Identify information sources	P_7	P_8	List of bench. partners	hard	
p_{11}	Analyse	P_8	P_{12}	Recommend. for action	hard	
p_{12}	Select the collection method	P_8	P_9	-	hard	
p_{13}	Contact partners for approval the benchmarking code of conduct	P_9	P_{10}	-	hard	
p_{14}	Analyse information	P_{10}	P_{11}	-	hard	
p_{15}	Provide recommendations for action	P_{11}	P_{12}	Recommend. for action	hard	
p_{16}	Adapt	P_{12}	P_{16}	-	hard	
p_{17}	Produce a report	P_{12}	P_{13}	Report	hard	
p_{18}	Make improvement recommendations	P_{13}	P_{14}	Recommend. improvement	hard	
p_{19}	Follow-up the results	P_{14}	P_{15}	-	hard	
p_{20}	Continue the benchmarking process	P_{15}	P_{16}	-	hard	

Table D.3 - Table of processes for the benchmarking process

Appendix E - Case study in PTC Windchill EIMS TM

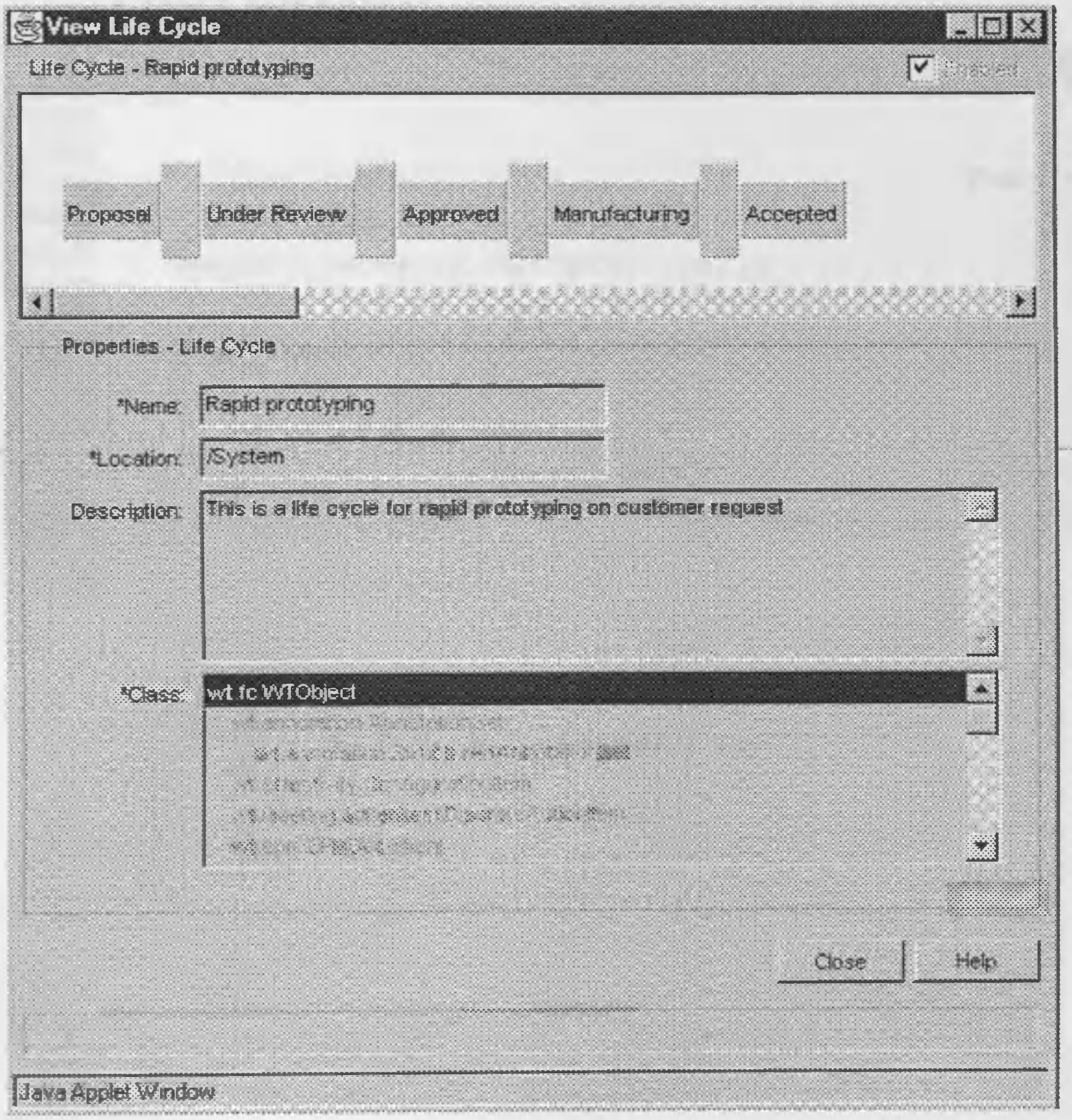


Fig. E.1– Rapid prototyping life cycle

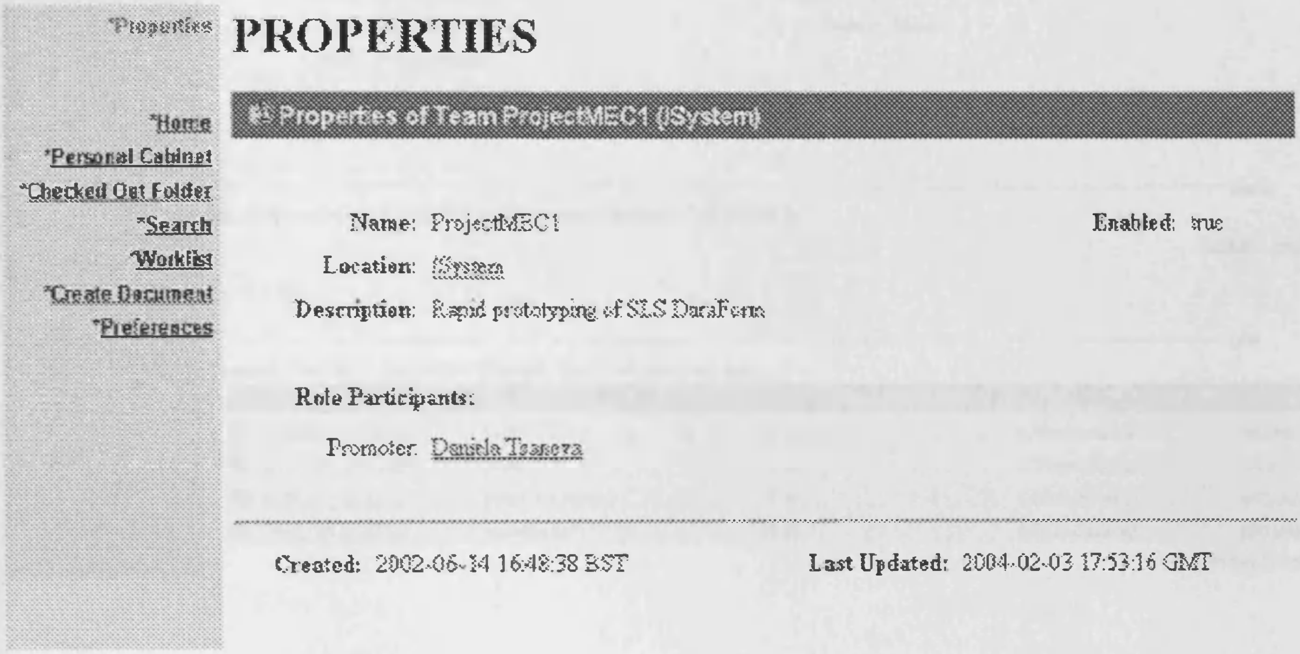


Fig. E.2 - The project MEC1 team

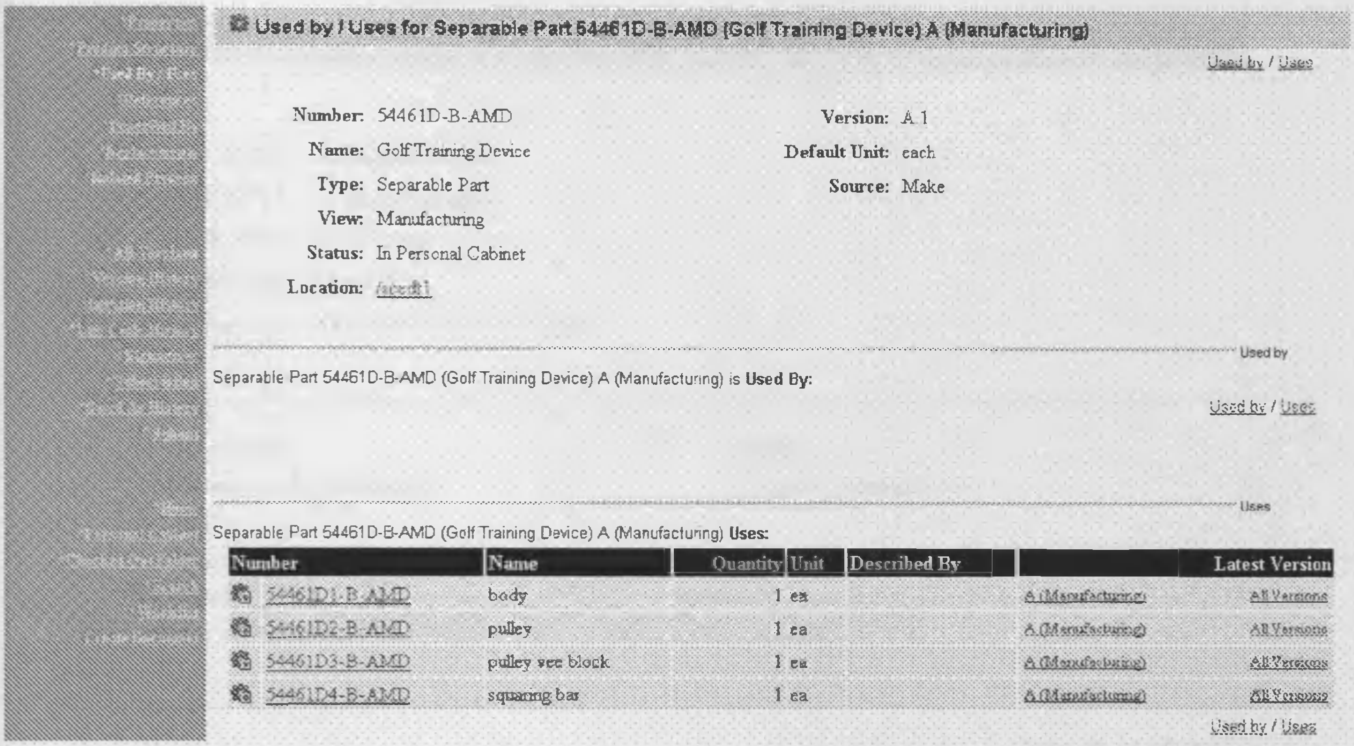


Fig. E.3 – Product structure

Properties of Document 6666 (part for production) A

Primary Content: thermoregulator.jpg
Latest Iteration: part for production
Format: JPEG Image
File Size: 31.8 KB
Last Updated: 2004-02-04 15:19:51 GMT

Number:	6666	**Version:**	A.1
Name:	part for production	**Type:**	Document
Title:			
Status:	Checked in		
Location:	/System		
Description:	A picture of thermoregulator		

Created By:	Daniela Tsaneva	**Created:**	2004-02-04 15:19:50 GMT
Updated By:	Daniela Tsaneva	**Last Updated:**	2004-02-04 15:19:50 GMT

Fig. E.4 – Document concerning the project

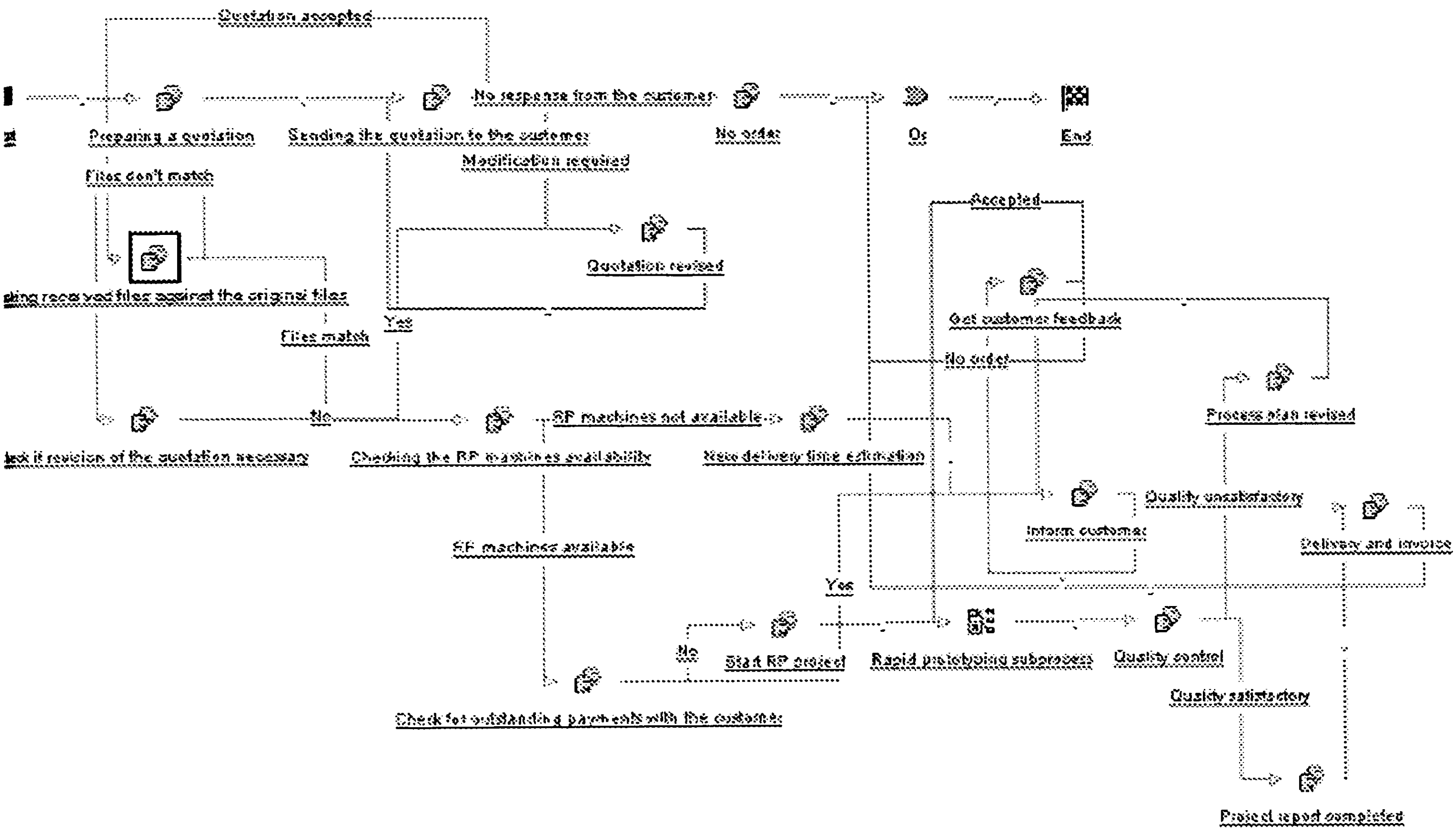


Fig. E.5 - The process diagram of the Main business process

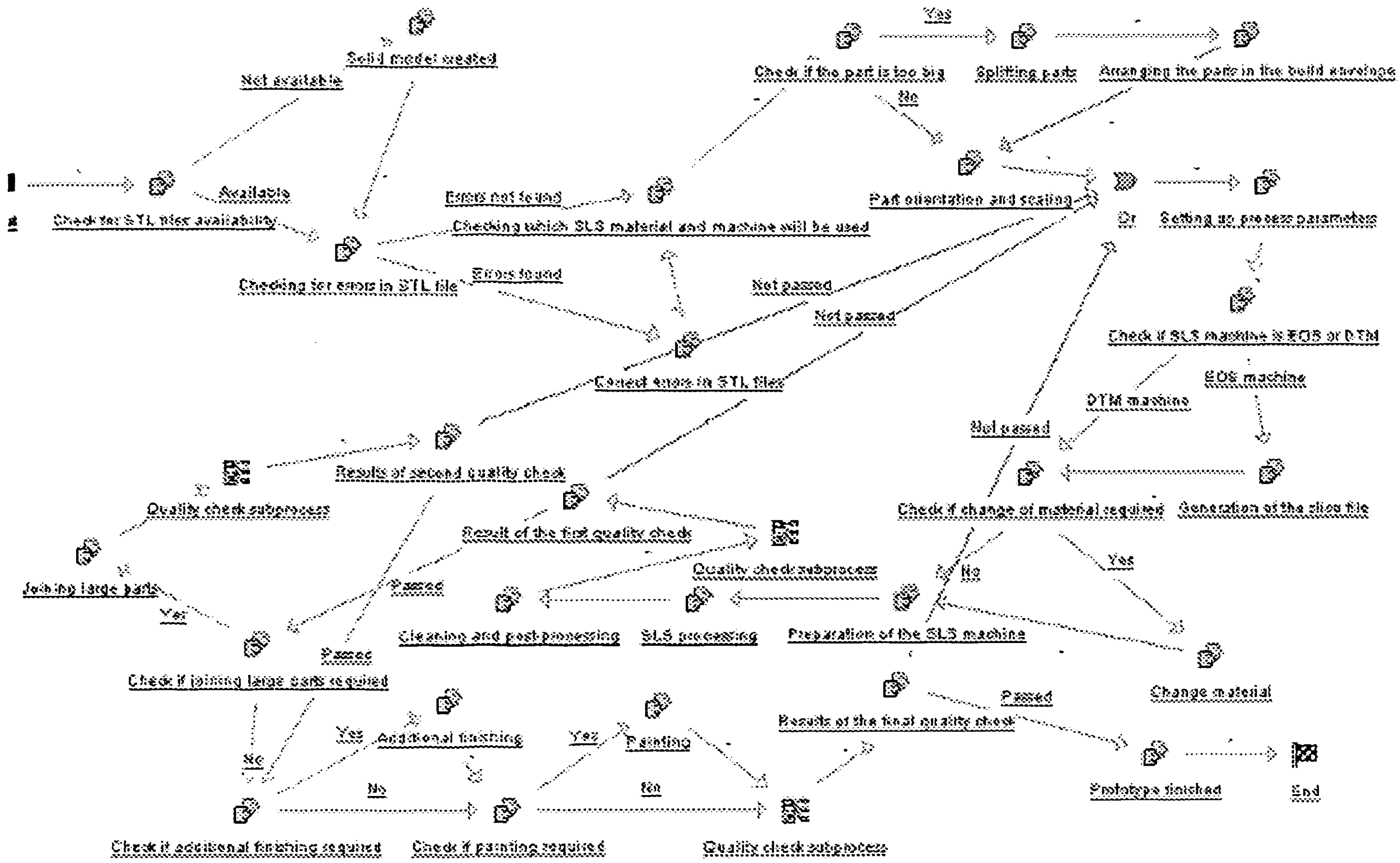


Fig. E.6 - The process diagram of the Prototyping subprocess

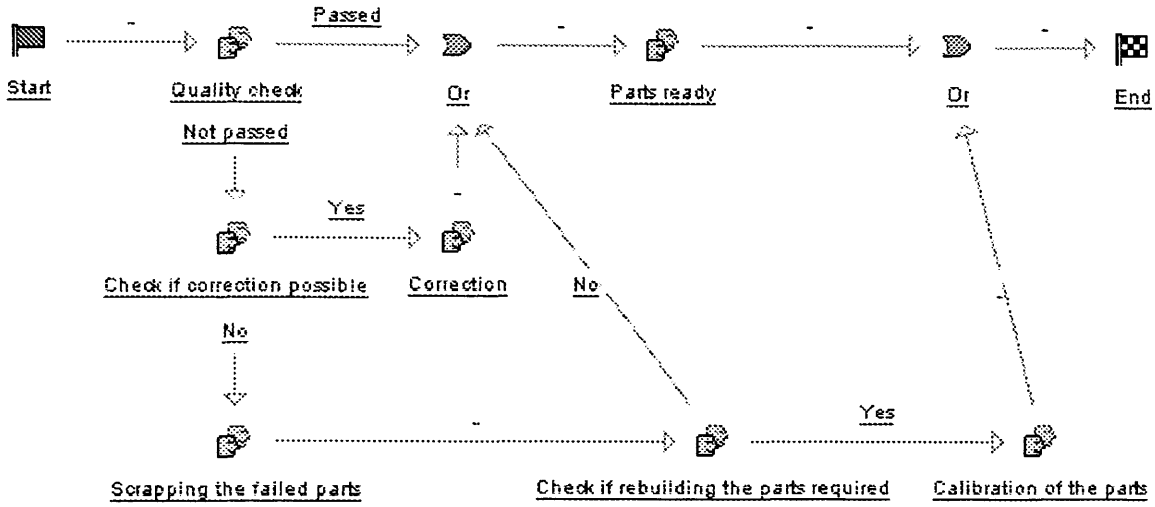


Fig. E.7 - The process diagram of the Quality check subprocess

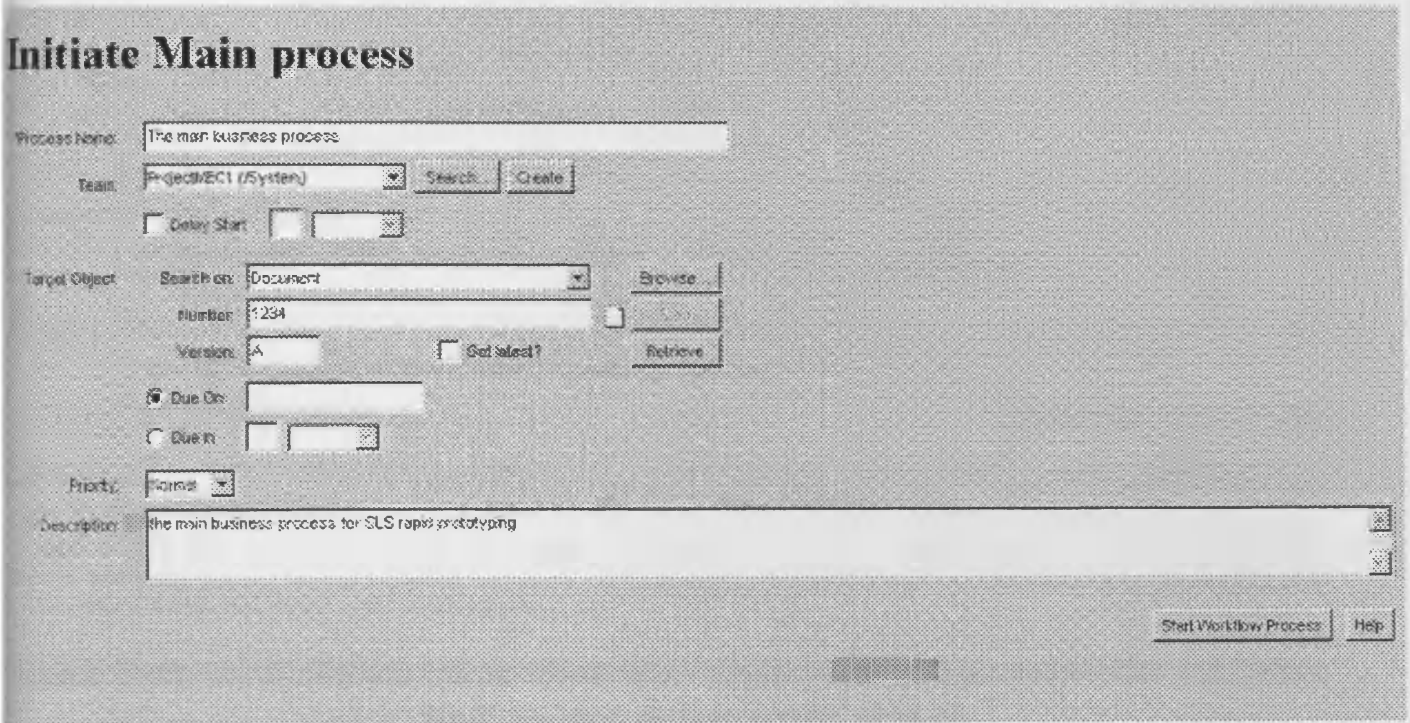


Fig. E.8 – Initiating the Main business process and starting the workflow

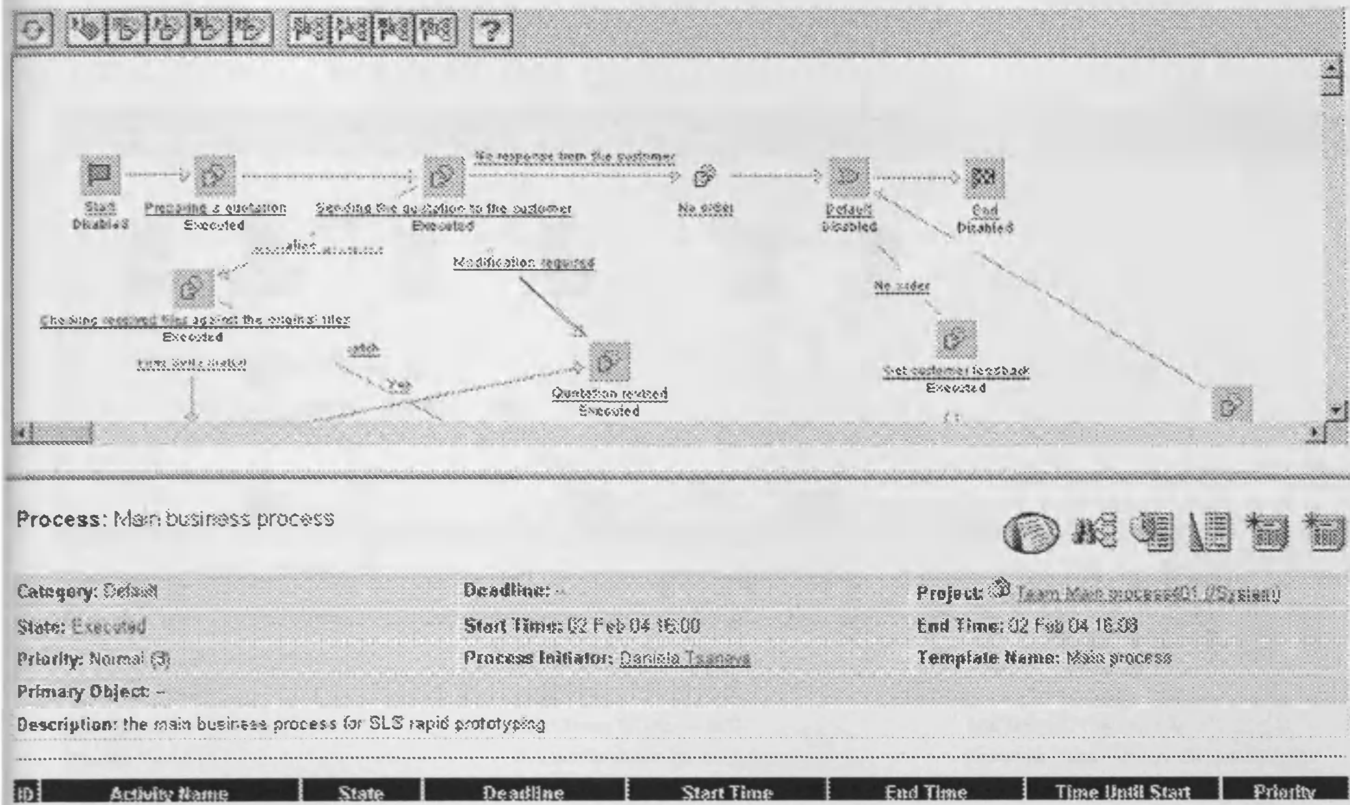


Fig. E.9 – Main business process executed

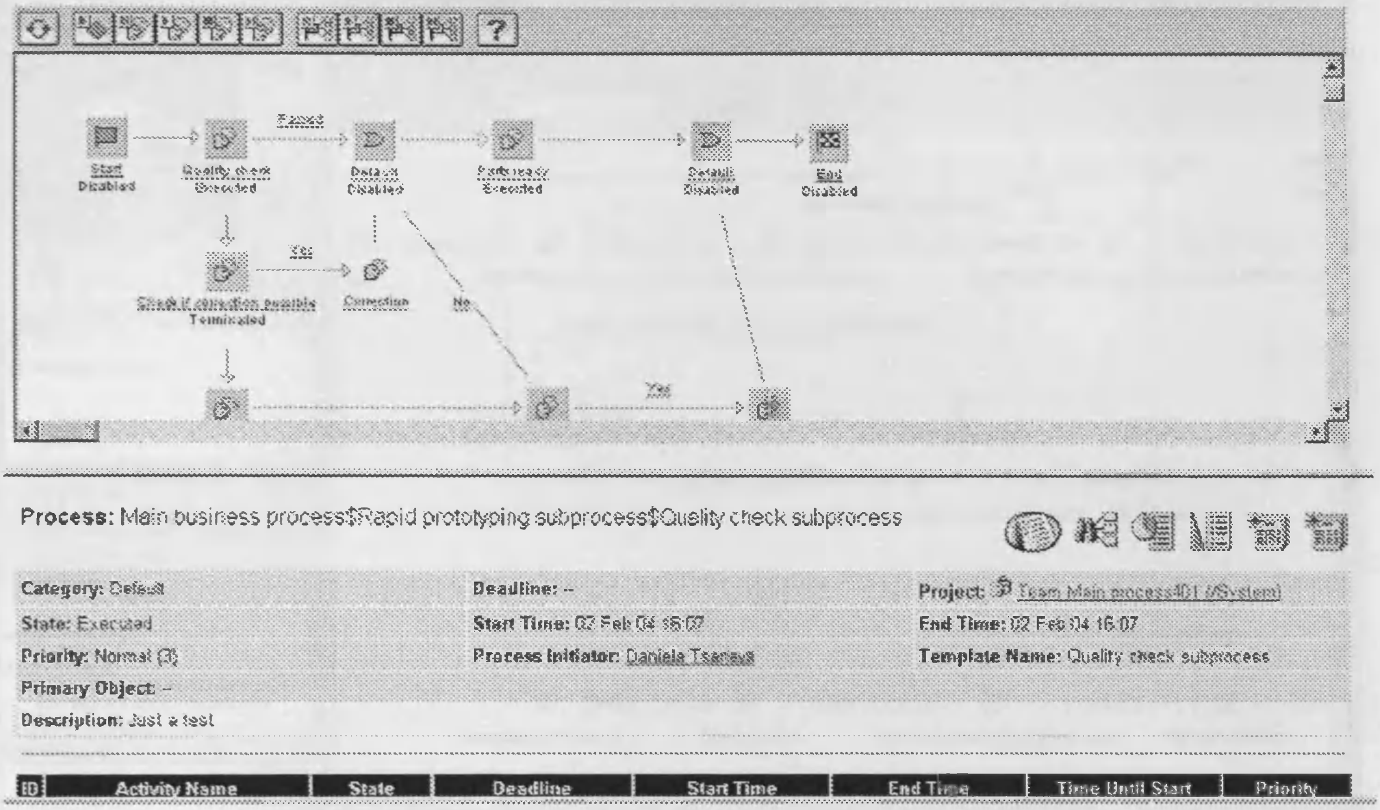


Fig. E.10 – Quality check subprocess executed

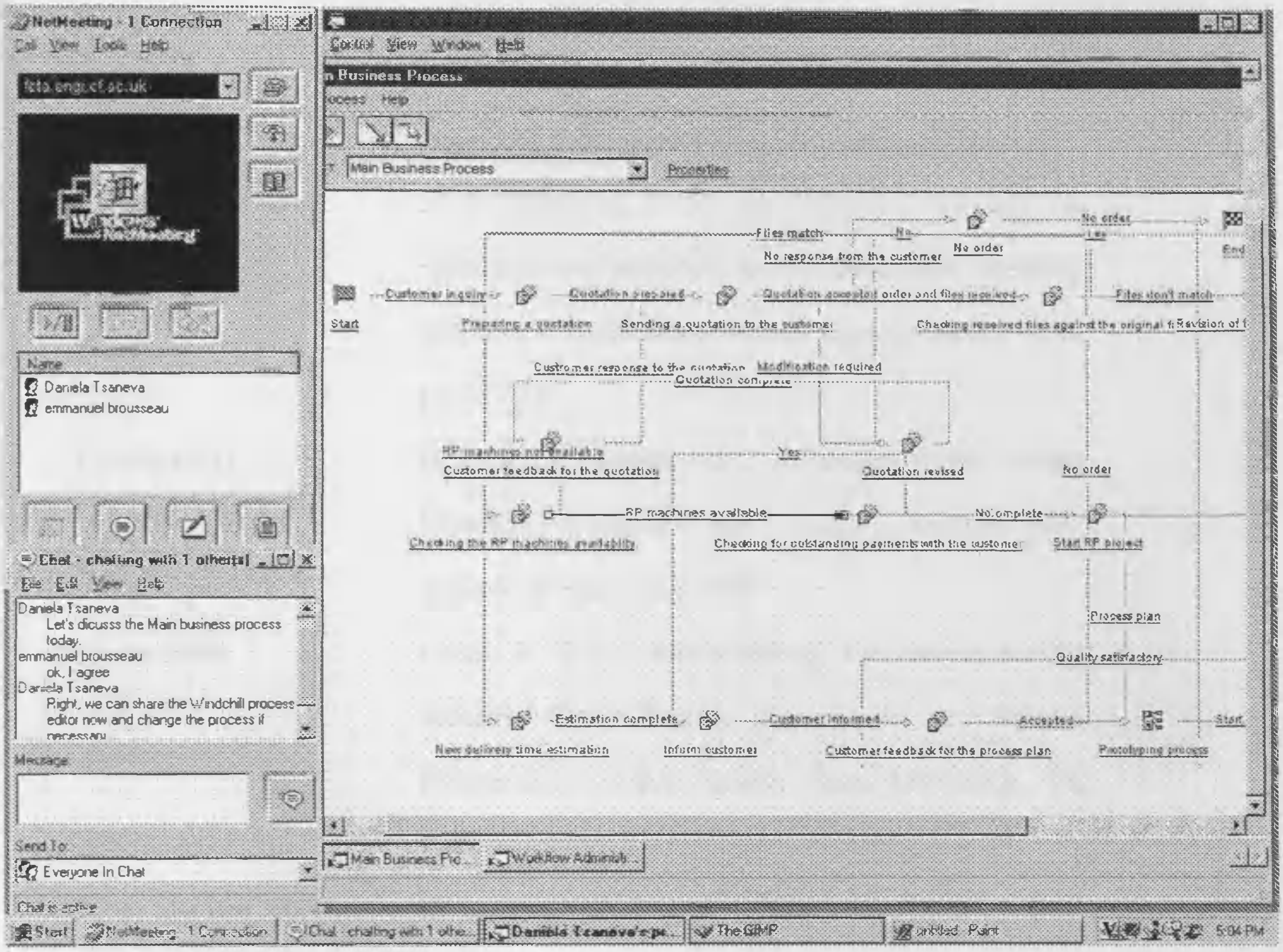


Fig. E.11 – Collaborative process modelling using NetMeeting Version 3.01 Microsoft Co. ™

REFERENCES

[ArgoUML] ArgoUML 0.12 – open source, http://argouml.tigris.org/

[Barros et al, 1998] A. P. Barros, A. H. M. ter Hofstede – "Towards the construction of workflow suitable conceptual modelling techniques", Information Systems Journal, October, 1998, pp. 313-337

[Booch 1998] G. Booch, I. Jacobson and J. Rumbaugh – "The Unified Modelling Language user's guide", Reading, MA: Addison-Wesley, USA, 1998

[Camp 1989] Camp, R. C. – "Benchmarking: The Search for the Industry Best Practice that Leads to Superior Performance", ASQC Quality Press, Milwaukee, WI, 1989

[Choy and Lee 2000] K. L. Choy, W. B. Lee – "Task allocation using case-based reasoning for distributed manufacturing systems", Logistics Information Management, vol. 13, number 3, 2000, pp. 167 - 176

[Davenport 1992] T. Davenport – "Process innovation: reengineering work through information technology", Cambridge, MA: Harvard Business School Books, USA, 1992

[Deming 1989] W. Edwards Deming – "Out of the Crisis", MIT 1989

[Detlor 2000] Brian Detlor – "The corporate portal as information infrastructure: towards a framework for portal design", International Journal of Information Management, vol. 20, 2000, pp. 91-101

[Drake 1998] P. R. Drake – "Using the Analytic Hierarchy process in Engineering Education", The International Journal of Engineering Education, vol. 14, No. 3, 1998, pp. 191-196

[Eriksson and Penker 2000] H. Eriksson, M. Penker – "Business modelling with UML: business patterns at work", John Wiley and Sons, Inc., 2000

[Evans and Lindsay 1996] J. R. Evans, W. M. Lindsay – "The management and control of quality", third edition, West Publishing Company, USA, 1996

[Firestone 1999] Joseph M. Firestone – "Defining the Enterprise Information Portal", white paper, Executive Information Systems, Inc., July 31, 1999, last accessed on February, 3rd, 2005 from http://www.hpcwire.com/dsstar/00/0822/102054.html

[Flores 1988] F. M. Flores, B. Hartfield, and T. Winograd – "Computer systems and design of organisational interaction", ACM Transactions on Office Information Systems, vol. 6, no. 2, 1988, pp. 153-172

[Frisco 1996] E. D. Falkenberg, et al – "A framework of information system concepts", IFIP WG 8.1, Task Group FRISCO, Leiden University, Leiden, The Netherlands, 1996

[Gouscos et al 2003] D. Gouscos, M. Kalikakis, M. Legal, S. Papadopoulou, G. Verginadis - "A performance and quality assessment model for one-stop government-to-business e-services", Business Excellence I, Performance Measures, Benchmarking and Best Practices in New Economy, University of Minho, Braga, Portugal, 2003, pp. 49 – 55, ISBN 972-8692-08-0

[Grigorova 2001] Katalina Grigorova, Workflow Representation within DBMS environment, CompSysTech'2001 - Bulgarian Computer Science Conference - 21-22.06.2001, Sofia, Bulgaria, pp. II.7-1-II.7-5

[Hammer and Champy 1994] M. Hammer, J. Champy – "Reengineering the corporation: a manifesto for business revolution", New York: Harper Business Books, USA, 1994

[Haque et al 2000] B. U. Haque, R. A. Belecheanu, R. J. Barson, K. S. Pawar – "Towards the application of case-based reasoning to decision-making in concurrent product development (concurrent engineering)", Elsevier Science, Knowledge-Based Systems, vol. 13, 2000, pp. 101-112

[Hayes 1999] Caroline C. Hayes – "Agents in a Nutshell – A Very Brief Introduction", IEEE Transactions on knowledge and data engineering, vol. 11, no. 1, 1999, pp. 127-132

[Hlupic 2001] V. Hlupic – "Current trends in business process modelling", International Journal of Simulation Systems, Science & Technology, vol. 2, no. 2, 2001, pp. 1-4, ISSN 1473-804x online, 1473-8031 print

[Hommes 2001] Bart-Jan Hommes – "The quality of business process modelling techniques", Delft, University of Technology, Netherlands, 2001

[Hommes and van Reijswoud 1999] B.-J. Hommes, V. Van Reijswoud – "The quality of business process modelling techniques", ISCO 1999: Leiden, The Netherlands, IFIP Conference Proceedings, Kluwer, volume 164, 2000, pp. 117-136

[Huang 2002] D. Huang – "Importing and Exporting XML Content using Microsoft Content Management Server 2001", Microsoft Corporation, USA, 2002, last accessed on February, 3, 2005 from http://msdn.microsoft.com/library/en-us/dnmscms01/html/cms_impexpxml.asp?frame=true

[Huang and Mak 2001a] G. Q. Huang, K. L. Mak – "Issues in the development and implementation of web applications for product design and manufacture", Computer Integrated Manufacturing, vol. 14, 2001, pp. 125-135

[Huang and Mak 2001b] G. Q. Huang, K. L. Mak – "Web-integrated manufacturing: recent developments and emerging issues", International Journal of Computer Integrated Manufacturing, 2001, vol. 14, no.1, pp. 3-13

[Huang and Mak 2001c] G. Q. Huang, K. L. Mak – "Modelling the customer-supplier interface over the world-wide web to facilitate early supplier involvement in the new product development", Proceedings of the Institution of Mechanical Engineers, Journal of Engineering Manufacture, Part B, 2001, pp. 759-769

[Huang et al 2000] G. Q. Huang, J. Huang, K. L. Mak – "Agent-based workflow management in collaborative product development on the Internet", Computer-Aided Design, vol. 32, 2000, pp. 133–144

[Irani et al 2000] Z. Irani, V. Hlupic, L. P. Baldwin, P. E. D. Love – "Re-engineering manufacturing processes through simulation modelling", Logistics Information Management, vol. 13, number 1, 2000, pp. 7-13

[Kaposi and Myers 2001] Agnes Kaposi, Margaret Myers – "Systems for all", Imperial College Press, 2001

[Kaposi et al, 1994] Agnes Kaposi, Margaret Myers – "Systems, models and measures", Springer, London, 1994

[Karacapilidis and Moraitis 2001] Karacapilidis, N. and Moraitis, P. – "Building an agent-mediated electronic commerce system with decision analysis features", Decision Support Systems, No. 32, 2001, pp. 53-69

[Kettinger et al 1997] Kettinger, W. J., Teng, J. T. C. And Guha, S. – "Business process change: a study of methodologies, techniques, and tools", MIS Quarterly, March, 1997, pp. 55-80

[Kolodner 1983] J. L. Kolodner –"Maintaining organisation in a dynamic long-term memory", Cognitive science, No. 7, 1983, pp. 243-280

[KTI 2001] "Knowledge-based process modeller (KPM)", Product of KTI – Knowledge Technology International, 2001

[Law 1988] D. Law – "Methods for comparing methods: Languages in software development", NCC Publications, Manchester, 1988

[Lehman 1997] M. M. Lehman – "Feedback in the software process", position paper, SEA Workshop: Research directions in software engineering – Imperial College, London, April 14 – 15th, 1997, Information and Software Technology, sp. is. on Software Maintenance, Elsevier, v. 38, n. 11, 1996, pp. 681 – 686

[Lesser 1999] Victor R. Lesser – "Cooperative Multiagent Systems: A Personal View of the State of the Art", IEEE Transactions on knowledge and data engineering, vol. 11, no.1, 1999, pp. 133-142

[Licea and Favela 2000] G. Licea, J. Favela – "An extensible platform for the development of synchronous groupware", Information and Software Technology, vol. 42, 2000, pp. 389-406

[Madhusudan and Zhao 2003] T. Madhusudan, J. Leon Zhao – "A Case-Based Framework for Workflow Model Managament", W. M. P. van der Aalst et al. (Eds.): BPM 2003, LNCS 2678, Springer-Verlag Berlin Heidelberg, 2003, pp. 354 – 369

[Miller et al 1997] Miller, J. A., Palaniswami, D., Sheth, A. P., Kochut, K. J., Singh H. – "WebWork: METEOR2's web-based workflow management system", Journal of Intelligent Information Systems, 1997, 10: pp. 185-215

[Murray 1999] G. Murray – "The Portal is the Desktop", Intraspect, Inc., 1999

[OpenText 1999] OpenText Corporation – "Corporate Portals – an Introduction", white paper, 1999

[Overmeer 1999] Mark A. C. J. Overmeer – "My personal search engine", Computer Networks, vol. 31, 1999, pp. 2263-2270

[Palmer and Palmer 1998] L. Palmer and R. Palmer – "Shared Desktop: A Collaborative Tool for Sharing 3-D Applications among Different Window Systems", Digital Technical Journal, 1998 – last accessed in August, 2004 from http://research.compaq.com/wrl/Decarchives/DTJR03/DTJR03HM.HTM

[Paolucci et al 1997] E. Paolucci, F. Donci, and V. Russi – "Redesigning organisations through business process re-engineering and object orientation", Proceedings of the European Conference on Information Systems, Cork, Ireland, 1997

[Porter and Bareiss 1986] B. W. Porter, E. R. Bareiss – "PROTOS: an experiment in knowledge acquisition for heuristic classification tasks", Proceedings of the First International Meeting on Advances in Learning (IMAL),, Les Arcs, France, 1986, pp. 159 – 174

[PTC 2001] Parametric Technology Corporation – "Windchill Business Administrator's Guide", Windchill Release 6.2, 2001, USA

[PTC 2002] Parametric Technology Corporation – "Windchill ProjectLink: Collaborative Project Management", white paper, October 2002, http://www.ptc.com/WCMS/files/3283en_file1.pdf

[PTC 2003] Parametric Technology Corporation – "Windchill Business Administrator's Guide", white paper, 2003, USA

[Reijswoud and Dietz 1998] V. E. van Reijswoud, J. L. G. Dietz – "DEMO modelling handbook", TU Delft, 1998

[Rezayat 2000] M. Rezayat – "The Enterprise-Web portal for life-cycle support", Computer-Aided Design, vol. 32, 2000

[Rezayat 2000a] M. Rezayat – "Knowledge-based product development using XML and KCs", Computer-Aided Design, vol. 32, 2000

[Ribeiro et al 2003] L. Ribeiro, J. A. Sarsfield Cabral – "A benchmarking methodology for metalcasting industry", Business Excellence'2003 conference proceedings, University of Minho, Braga, Portugal, 2003, pp. 218-224

[Rice, 1996] Rice, V. – "Building the case for your intranet", PC Week, April, 29th, 1996

[Riesbeck and Schank 1989] C. K. Riesbeck, R. Schank – "Inside case-based reasoning", Northvale, NJ: Lawrence Erlbaum Associates, 1989

[Saaty 1980] T. L. Saaty – "The Analytic Hierarchy Process", McGraw-Hill, New York, USA, 1980

[SAP R/3 2000] "MySAP.com Workplace Enterprise Portal", white paper,

	2000
[Schank and Abelson 1977]	R. Schank, R. Abelson – "Scripts, plans, goals and understanding", Hillsdale, NJ: Lawrence Erlbaum Associates, 1977
[Shilakes and Tylman 1998]	C. C. Shilakes, J. Tylman – "Enterprise Information Portals. In: In-depth Report", Industry Overview, Merrill Lynch & Co. Global Securities Research & Economics Group, 1998, last accessed on April 17, 2001, from http://www.sagemaker.com/company/WhitePapers/eip_indepth.pdf
[Small, 1999]	Small, P. – "Magical A-life avatars", Greenwich, CT: Manning Publications, p.104, 1999
[Spendolini 1992]	Spendolini, M. – "The Benchmarking Book", American Benchmarking Association, New York, 1992
[Sternemann and Zelm 1999]	K.-H. Sternemann, M. Zelm – "Context sensitive provision and visualisation of enterprise information with a hypermedia based system", Computers in industry, vol. 40, 1999, pp. 173 - 184
[Tam et al 2000]	S. Tam, W. B. Lee, W. W. C. Chung, H. C. W. Lau – "An object-based process planning and scheduling model in a product design environment", Logistics Information Management, vol. 13, number 4, 2000, pp. 191 – 200

[Thyfault, 1996] Thyfault, M. E. – "The intranet rolls in", Information Week, Cover story, 1996

[Tumay 1995] K. Tumay – "Business process simulation" in Alexopolus, A., Kang, K., Lilegdon, W. R. and Goldman, D. (Eds), Proceedings of the WSC'95 – Winter Simulation Conference, Washington DC, USA, SCS, 1995

[Vernadat 1996] Francois B. Vernadat – "Enterprise Modelling and Integration – principles and applications", Chapman & Hall, 1996

[Vuksic et al 2001] V. Vuksic, M. Stemberger, J. Jaklic – "Simulation modelling towards e-business models development", International Journal of Simulation Systems, Science & Technology, vol. 2, no. 2, 2001, pp. 16-29, ISSN 1473-804x online, 1473-8031 print

[Watson 1997] Ian Watson – "Applying Case-Based Reasoning: Techniques for Enterprise Systems", Morgan Kaufmann Publishers, Inc., San Francisco, California, USA, 1997

[Watson and Fenner 2000] James Watson, Joe Fenner – "Understanding portals", Information Management Journal, Prairie Village, July, 2000, pp. 18-22

[Wells 2000] M. G. Wells – "Business process re-engineering implementations using Internet technology", Business Process Management Journal, vol. 6, No. 2, 2000, pp. 164-184

[Whitlock 2003] N. Walker Whitlock – "Business process management with IBM Holosofx", Casaflora Communications, USA, 2003, http://www-106.ibm.com/developerworks/ibm/library/i-holo/

[Yu et al 2003] Ren Yu, B. Iung, H. Panetto – "A multi-agent based E-maintenance system with case-based reasoning decision support", Engineering Applications of Artificial Intelligence, Elsevier Ltd., 2003, vol. 16, pp. 321-333